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密级 ★ | 项目组公开

智能合约审计报告

安全状态

安全

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版本说明

修订内容	时间	修订者	版本号
编写文档	20210809	知道创宇区块链安全研究团队	V1.1

文档信息

文档名称	文档版	文档编号	保密级别
Channels 智能合约审计报告	V1.0	4c533d00766c4b2a9761fad5da78b56f	项目组公开

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目录

1. 综述

本次报告有效测试时间是从 2021 年 1 月 13 日开始到 2021 年 1 月 14 日结束，在此期间针对 **Channels 智能合约代码**的安全性和规范性进行审计并以此作为报告统计依据。

本次智能合约安全审计的范围，不包含外部合约调用，不包含未来可能出现的新型攻击方式，不包含合约升级或篡改后的代码(随着项目方的发展，智能合约可能会增加新的 pool、新的功能模块，新的外部合约调用等)，不包含前端安全与服务器安全。

此次测试中，知道创宇工程师对智能合约常见漏洞（见第三章节）和常见漏洞（见第四章节）进行了全面的分析，暂时综合评定为 。

本次智能合约安全审计结果： 通过

由于本次测试过程在非生产环境下进行，所有代码均为最新备份，测试过程均与相关接口人进行沟通，并在操作风险可控的情况下进行相关测试操作，以规避测试过程中的生产运营风险、代码安全风险。

本次审计的报告信息：

报告编号： 4c533d00766c4b2a9761fad5da78b56f

报告查询地址链接：

https://attest.im/attestation/searchResult?qurey=4c533d00766c4b2a9761fad5da78b56f

本次审计的目标信息：

条目	描述
Token 名称	CAN
项目名称	Channels
代码类型	代币代码、预言机代码
代码语言	solidity

合约文件及哈希：

合约文件	MD5
ChannelsAnchoredOracle.sol	AEDA3FDC82C45AC6BBA7ADDA0FF4A912
ChannelsOracleConfig.sol	483C9E3E5E1E0AC249E52673AA953B83
OpenOracleData.sol	8E06C0086F2781DFC1B4AD3F87EDB3D8
OpenOraclePriceData.sol	B404994AED301F1D5D53C6A78ABC62DC
Can.sol	22E90B6D10F2C73DBD0252013B0C3E21
CarefulMath.sol	404638103FFC07C8D71D96B7FFE397CB
CErc20.sol	CB43F7F7B16EE6572BAD7AC997018897
CErc20Delegate.sol	25494E990B8BD3D9F35E9FAA58653EDD
CErc20Delegator.sol	22D8F4A500BB667EE852B0F4DB650181
CHT.sol	9D3C8C30A3F049F36873F74F73518E0D
Comptroller.sol	71DC6F9E0D2CF3EB4EEA1044FFAE4627
ComptrollerInterface.sol	6CDB79A0889D8C37C8C5642D0813B37A
ComptrollerStorage.sol	AFAC2D1A4B63F5DBB87466614A5077B3
CToken.sol	D9ABD6093AD4F8467E7F65A6F2DE1E59
CTokenInterfaces.sol	C5C81B131F5B7BBF75D0C6F7128E8AAF
EIP20Interface.sol	FA93E469FB558E63A43784A83F62FC89
EIP20NonStandardInterface. sol	233B54BA1F055B8C2B9EA1C1DD3608F3
ErrorReporter.sol	95D03468BA60073770D7D8040E24A602
Exponential.sol	778D6C3E8CD5F4FFF4188235A2A287C3

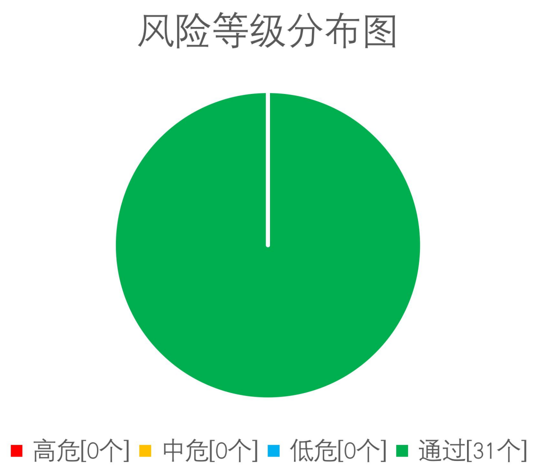
InterestRateModel.sol	B04DC93642AA590108317297C6F6960F
Maximillion.sol	FD3DBE38EB723C295C89A4B0B118C6B9
Reservoir.sol	43D75B1F2C0D3DE758C4DF36B5A71262
SafeMath.sol	51E3BCE6F64C8CBDB9F6A6C4D8CCAA1B
Unitroller.sol	481805E9C40A023D03E6D832A9FFD667
WhitePaperInterestRateModel.sol	28246D4EB4D485F312AEBAF47CC6716D

2. 代码漏洞分析

2.1 漏洞等级分布

本次漏洞风险按等级统计：

安全风险等级个数统计表			
高危	中危	低危	通过
0	0	0	31



2.2 审计结果汇总说明

审计结果			
审计项目	审计内容	状态	描述
业务安全性检测	预言机配置模块	通过	经检测，不存在该安全问题。
	预言机锚定询价功能	通过	经检测，不存在该安全问题。
	预言机锚定喂价功能	通过	经检测，不存在该安全问题。
	代币合约各功能	通过	经检测，不存在该安全问题。
代码基本漏洞检测	编译器版本安全	通过	经检测，不存在该安全问题。
	冗余代码	通过	经检测，不存在该安全问题。
	安全算数库的使用	通过	经检测，不存在该安全问题。
	不推荐的编码方式	通过	经检测，不存在该安全问题。
	require/assert 的合理使用	通过	经检测，不存在该安全问题。
	fallback 函数安全	通过	经检测，不存在该安全问题。
	tx.orgin 身份验证	通过	经检测，不存在该安全问题。
	owner 权限控制	通过	经检测，不存在该安全问题。
	gas 消耗检测	通过	经检测，不存在该安全问题。
	call 注入攻击	通过	经检测，不存在该安全问题。
	低级函数安全	通过	经检测，不存在该安全问题。
	增发代币漏洞	通过	经检测，不存在该安全问题。
	访问控制缺陷检测	通过	经检测，不存在该安全问题。
	数值溢出检测	通过	经检测，不存在该安全问题。
	算数精度误差	通过	经检测，不存在该安全问题。
	错误使用随机数检测	通过	经检测，不存在该安全问题。
	不安全的接口使用	通过	经检测，不存在该安全问题。
	变量覆盖	通过	经检测，不存在该安全问题。
	未初始化的存储指针	通过	经检测，不存在该安全问题。

	返回值调用验证	通过	经检测，不存在该安全问题。
	交易顺序依赖检测	通过	经检测，不存在该安全问题。
	时间戳依赖攻击	通过	经检测，不存在该安全问题。
	拒绝服务攻击检测	通过	经检测，不存在该安全问题。
	假充值漏洞检测	通过	经检测，不存在该安全问题。
	重入攻击检测	通过	经检测，不存在该安全问题。
	重放攻击检测	通过	经检测，不存在该安全问题。
	重排攻击检测	通过	经检测，不存在该安全问题。

3. 业务安全性检测

3.1. 预言机配置模块【通过】

审计分析：项目合约中使用 ChannelsOracleConfig 作为预言机配置模块，经审计，该模块设计合理，cToken 配置正确。

```
contract ChannelsOracleConfig {
    /// @dev Describe how to interpret the fixedPrice in the TokenConfig.
    enum PriceSource {// knownsec //价格修正源配置
        FIXED_ETH, /// implies the fixedPrice is a constant multiple of the ETH price (which varies)//knownsec  枚举类型  FIXED_ETH  未删除
        FIXED_USD, /// implies the fixedPrice is a constant multiple of the USD price (which is 1)
        REPORTER     /// implies the price is set by the reporter
    }

    /// @dev Describe how the USD price should be determined for an asset.
    ///  There should be 1 TokenConfig object for each supported asset, passed in the constructor.
    struct TokenConfig {// knownsec //TokenConfig  结构体
        address cToken;
        address underlying;
        bytes32 symbolHash;
        uint256 baseUnit;
        PriceSource priceSource;
        uint256 fixedPrice;
        string symbolName;
    }
…
…
}
```

安全建议：无。

3.2. 预言机锚定询价功能【通过】

审计分析：项目合约中使用 price 来获取官方价格，经过多重调用，最终使用 *getTokenConfig* 来获取价格，经审计，该功能逻辑设置合理，用户可控参数正常。

```
        function price(string memory symbol) external view returns (uint) {//knownsec 外部利用 symbol 查询官方价格
            TokenConfig memory config = getTokenConfigBySymbol(symbol);
            return priceInternal(config);
    }

    function priceInternal(TokenConfig memory config) internal view returns (uint) {//knownsec 返回 6 位小数的 USD 价格未处理 FIXED_ETH
            if (config.priceSource == PriceSource.REPORTER) return prices[config.symbolHash];
            if (config.priceSource == PriceSource.FIXED_USD) return config.fixedPrice;
    }
```

安全建议：无。

3.3. 预言机锚定喂价功能【通过】

审计分析：项目合约中使用 postPrices 来进行喂价，同时采取了 reporter 喂价的方式阻隔掉其他币种影响。经审计，该功能权限控制合理，逻辑处理正常。

```
    function postPrices(bytes[] calldata messages, bytes[] calldata signatures, string[] calldata symbols) external {//knownsec 喂价函数
            require(messages.length == signatures.length, "messages and signatures must be 1:1");
            require(msg.sender == reporter, "msg sender must be reporter ");//knownsec reporter 才可进行喂价
```

```
        // Save the prices
        for (uint i = 0; i < messages.length; i++) {
            priceData.put(messages[i], signatures[i]);
        }

        // Try to update the view storage
        for (uint i = 0; i < symbols.length; i++) {
            postPriceInternal(symbols[i]);
        }
    }

    function postPriceInternal(string memory symbol) internal {//knownsec 内部喂价函数
        TokenConfig memory config = getTokenConfigBySymbol(symbol);//knownsec config 获取
        require(config.priceSource == PriceSource.REPORTER, "only reporter prices get posted");//knownsec report 可用
        bytes32 symbolHash = keccak256(abi.encodePacked(symbol));//knownsec 获取 symbol 哈希值
        uint reporterPrice = priceData.getPrice(reporter, symbol);//knownsec 报告着价格

        queryPriceBySymbol(config.symbolName);//knownsec 中心喂价 放入_price

        uint anchorPrice;//knownsec 报价地址报价
        anchorPrice = parseInt(_price, 6); //knownsec String 类型转化

        if (isWithinAnchor(reporterPrice, anchorPrice)) {
            prices[symbolHash] = reporterPrice;//knownsec 官方价格修改
            emit PriceUpdated(symbol, reporterPrice);//knownsec 事件记录
        } else {
            emit PriceGuarded(symbol, reporterPrice, anchorPrice);
            revert("reporterPrice is not with in Anchor");//knownsec 报告价格超出锚定的百分比公差
        }
    }

    function isWithinAnchor(uint reporterPrice, uint anchorPrice) internal view returns (bool) { //knownsec 价格限制
        if (reporterPrice > 0) {
            uint anchorRatio = mul(anchorPrice, 100e16) / reporterPrice;//konwnsec //计算百分比公差
            return anchorRatio <= upperBoundAnchorRatio && anchorRatio >= lowerBoundAnchorRatio;
        }
        return false;
    }
```

安全建议：无。

3.4. 代币合约各功能【通过】

审计分析：项目合约中使用 Can 合约作为代币合约，该合约依赖 compound 合约进行开发，经审计，合约各功能设计正常，权限控制合理。

```
    function allowance(address account, address spender) external view returns (uint) {
        return allowances[account][spender];
    }
    function approve(address spender, uint rawAmount) external returns (bool) {
        uint96 amount;
        if (rawAmount == uint(-1)) {
            amount = uint96(-1);
        } else {
            amount = safe96(rawAmount, "Can::approve: amount exceeds 96 bits");
        }
        allowances[msg.sender][spender] = amount;
        emit Approval(msg.sender, spender, amount);
        return true;
    }
    function balanceOf(address account) external view returns (uint) {//knwonsec 查询余额
        return balances[account];
    }
    function transfer(address dst, uint rawAmount) external returns (bool) {//knownsec 转账函数
        uint96 amount = safe96(rawAmount, "Can::transfer: amount exceeds 96 bits");
        _transferTokens(msg.sender, dst, amount);
        return true;
    }
    function transferFrom(address src, address dst, uint rawAmount) external returns (bool) {//knownsec 授权转账函数
        address spender = msg.sender;
        uint96 spenderAllowance = allowances[src][spender];
        uint96 amount = safe96(rawAmount, "Can::approve: amount exceeds 96 bits");

        if (spender != src && spenderAllowance != uint96(-1)) {
            uint96 newAllowance = sub96(spenderAllowance, amount, "Can::transferFrom: transfer amount exceeds spender allowance");
            allowances[src][spender] = newAllowance;

            emit Approval(src, spender, newAllowance);
        }
        _transferTokens(src, dst, amount);
        return true;
    }
```

安全建议：无。

4. 代码基本漏洞检测

4.1. 编译器版本安全【通过】

检查合约代码实现中是否使用了安全的编译器版本

检测结果：经检测，智能合约代码中制定了编译器版本 0.5.15 以上，不存在该安全问题。

安全建议：无。

4.2. 冗余代码【通过】

检查合约代码实现中是否包含冗余代码

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.3. 安全算数库的使用【通过】

检查合约代码实现中是否使用了 SafeMath 安全算数库

检测结果：经检测，智能合约代码中已使用 SafeMath 安全算数库，不存在该安全问题。

安全建议：无。

4.4. 不推荐的编码方式【通过】

检查合约代码实现中是否有官方不推荐或弃用的编码方式

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.5. require/assert 的合理使用【通过】

检查合约代码实现中 require 和 assert 语句使用的合理性

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.6. fallback 函数安全【通过】

检查合约代码实现中是否正确使用 fallback 函数

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.7. tx.origin 身份验证【通过】

tx.origin 是 Solidity 的一个全局变量，它遍历整个调用栈并返回最初发送调用（或事务）的帐户的地址。在智能合约中使用此变量进行身份验证会使合约容易受到类似网络钓鱼的攻击。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.8. owner 权限控制【通过】

检查合约代码实现中的 owner 是否具有过高的权限。例如，任意修改其他账户余额等。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.9. gas 消耗检测【通过】

检查 gas 的消耗是否超过区块最大限制

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.10. call 注入攻击【通过】

call 函数调用时，应该做严格的权限控制，或直接写死 call 调用的函数。

检测结果：经检测，智能合约未使用 call 函数，不存在此漏洞。

安全建议：无。

4.11. 低级函数安全【通过】

检查合约代码实现中低级函数（call/delegatecall）的使用是否存在安全漏洞

call 函数的执行上下文是在被调用的合约中；而 delegatecall 函数的执行上下文是在当前调用该函数的合约中

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.12. 增发代币漏洞【通过】

检查在初始化代币总量后，代币合约中是否存在可能使代币总量增加的函

数。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.13. 访问控制缺陷检测【通过】

合约中不同函数应设置合理的权限

检查合约中各函数是否正确使用了 public、private 等关键词进行可见性修饰，检查合约是否正确定义并使用了 modifier 对关键函数进行访问限制，避免越权导致的问题。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：该问题不属于安全问题，但部分交易所会限制增发函数的使用，具体情况需根据交易所的要求而定。

4.14. 数值溢出检测【通过】

智能合约中的算数问题是指整数溢出和整数下溢。

Solidity 最多能处理 256 位的数字（2^256−1），最大数字增加 1 会溢出得到 0。同样，当数字为无符号类型时，0 减去 1 会下溢得到最大数字值。

整数溢出和下溢不是一种新类型的漏洞，但它们在智能合约中尤其危险。溢出情况会导致不正确的结果，特别是如果可能性未被预期，可能会影响程序的可靠性和安全性。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.15. 算术精度误差【通过】

Solidity 作为一门编程语言具备和普通编程语言相似的数据结构设计，比如：变量、常量、函数、数组、函数、结构体等等，Solidity 和普通编程语言也有一个较大的区别——Solidity 没有浮点型，且 Solidity 所有的数值运算结果都只会是整数，不会出现小数的情况，同时也不允许定义小数类型数据。合约中的数值运算必不可少，而数值运算的设计有可能造成相对误差，例如同级运算：5/2*10=20，而 5*10/2=25，从而产生误差，在数据更大时产生的误差也会更大，更明显。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.16. 错误使用随机数【通过】

智能合约中可能需要使用随机数，虽然 Solidity 提供的函数和变量可以访问明显难以预测的值，如 block.number 和 block.timestamp，但是它们通常或者比看起来更公开，或者受到矿工的影响，即这些随机数在一定程度上是可预测的，所以恶意用户通常可以复制它并依靠其不可预知性来攻击该功能。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.17. 不安全的接口使用【通过】

检查合约代码实现中是否使用了不安全的接口

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.18. 变量覆盖【通过】

检查合约代码实现中是否存在变量覆盖导致的安全问题

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.19. 未初始化的储存指针【通过】

在 solidity 中允许一个特殊的数据结构为 struct 结构体，而函数内的局部变量默认使用 storage 或 memory 储存。

而存在 storage(存储器)和 memory(内存)是两个不同的概念，solidity 允许指针

指向一个未初始化的引用，而未初始化的局部 stroage 会导致变量指向其他储存变量，导致变量覆盖，甚至其他更严重的后果，在开发中应该避免在函数中初始化 struct 变量。

检测结果：经检测，智能合约代码不使用结构体，不存在该问题。

安全建议：无。

4.20. 返回值调用验证【通过】

此问题多出现在和转币相关的智能合约中，故又称作静默失败发送或未经检查发送。

在 Solidity 中存在 transfer()、send()、call.value()等转币方法，都可以用于向某一地址发送 Ether，其区别在于： transfer 发送失败时会 throw，并且进行状态回滚；只会传递 2300gas 供调用，防止重入攻击；send 发送失败时会返回 false；只会传递 2300gas 供调用，防止重入攻击；call.value 发送失败时会返回 false；传递所有可用 gas 进行调用（可通过传入 gas_value 参数进行限制），不能有效防止重入攻击。

如果在代码中没有检查以上 send 和 call.value 转币函数的返回值，合约会继续执行后面的代码，可能由于 Ether 发送失败而导致意外的结果。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.21. 交易顺序依赖【通过】

由于矿工总是通过代表外部拥有地址（EOA）的代码获取 gas 费用，因此用

户可以指定更高的费用以便更快地开展交易。由于币安智能链是公开的，每个人都可以看到其他人未决交易的内容。这意味着，如果某个用户提交了一个有价值的解决方案，恶意用户可以窃取该解决方案并以较高的费用复制其交易，以抢占原始解决方案。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.22. 时间戳依赖攻击【通过】

数据块的时间戳通常来说都是使用矿工的本地时间，而这个时间大约能有 900 秒的范围波动，当其他节点接受一个新区块时，只需要验证时间戳是否晚于之前的区块并且与本地时间误差在 900 秒以内。一个矿工可以通过设置区块的时间戳来尽可能满足有利于他的条件来从中获利。

检查合约代码实现中是否存在有依赖于时间戳的关键功能

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.23. 拒绝服务攻击【通过】

在以太坊的世界中，拒绝服务是致命的，遭受该类型攻击的智能合约可能永远无法恢复正常工作状态。导致智能合约拒绝服务的原因可能有很多种，包括在作为交易接收方时的恶意行为，人为增加计算功能所需 gas 导致 gas 耗尽，滥用访问控制访问智能合约的 private 组件，利用混淆和疏忽等等。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.24. 假充值漏洞【通过】

在代币合约的 transfer 函数对转账发起人(msg.sender)的余额检查用的是 if 判断方式，当 balances[msg.sender] < value 时进入 else 逻辑部分并 return false，最终没有抛出异常，我们认为仅 if/else 这种温和的判断方式在 transfer 这类敏感函数场景中是一种不严谨的编码方式。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.25. 重入攻击检测【通过】

重入漏洞是最著名的以太坊智能合约漏洞，曾导致了以太坊的分叉（The DAO hack）。

在 Solidity 中，调用其他地址的函数或者给合约地址转账，都会把自己的地址作为被调合约的 msg.sender 传递过去。此时，如果传递的 energy 足够的话，就可能会被对方进行重入攻击，在波场中对合约地址调用 transfer/sender，只会传递 2300 的 Energy，这不足以发起一次重入攻击。所以要一定避免通过 call.value 的方式，调用未知的合约地址。因为 call.value 可以传入远大于 2300 的 energy。

检测结果：经检测，智能合约代码中不存在该安全问题。

安全建议：无。

4.26. 重放攻击检测【通过】

合约中如果涉及委托管理的需求，应注意验证的不可复用性，避免重放攻击

在资产管理体系中，常有委托管理的情况，委托人将资产给受托人管理，委托人支付一定的费用给受托人。这个业务场景在智能合约中也比较普遍。。

检测结果：经检测，智能合约未使用 call 函数，不存在此漏洞。

安全建议：无。

4.27. 重排攻击检测【通过】

重排攻击是指矿工或其他方试图通过将自己的信息插入列表(list)或映射(mapping)中来与智能合约参与者进行“竞争”，从而使攻击者有机会将自己的信息存储到合约中。

检测结果:经检测，智能合约代码中不存在相关漏洞。

安全建议:无。

5. 附录 A：合约代码

本次测试代码来源：

```
ChannelsAnchoredOracle.sol
pragma solidity ^0.6.10;
pragma experimental ABIEncoderV2;

import "./OpenOraclePriceData.sol";
import "./ChannelsOracleConfig.sol";

contract ChannelsAnchoredOracle is ChannelsOracleConfig {// knownsec 继承 ChannelsOracleConfig

    /// @notice The Open Oracle Price Data contract
    OpenOraclePriceData public immutable priceData;// knownsec 声明预言机价格数据协议

    /// @notice The Open Oracle Reporter
    address public immutable reporter;

    /// @notice The highest ratio of the new price to the anchor price that will still trigger the price to be updated
    uint public immutable upperBoundAnchorRatio;// knownsec 锚定价格的最高比率

    /// @notice The lowest ratio of the new price to the anchor price that will still trigger the price to be updated
    uint public immutable lowerBoundAnchorRatio;// knownsec 锚定价格的最低比率

    /// @notice Official prices by symbol hash, default mul 1e6
    mapping(bytes32 => uint) public prices;// knownsec 官方价格

    /// @notice Oracle Args
    string _price;// knownsec 定义预言机相关参数 价格 token 报价 报价地址
    /// @notice Oracle Args
    ERC20 _token;
    /// @notice Oracle Args
    QuotedPrice _priceContract;
    /// @notice Oracle Args
    address _priceAddress;

    /// @notice The event emitted when new prices are posted but the stored price is not updated due to the
anchor
    event PriceGuarded(string symbol, uint reporter, uint anchor);

    /// @notice The event emitted when the stored price is updated
    event PriceUpdated(string symbol, uint price);
    /**
     * @notice Construct a uniswap anchored view for a set of token configurations
     * @dev Note that to avoid immature TWAPs, the system must run for at least a single anchorPeriod before
using.
     * @param reporter_ The reporter whose prices are to be used
     * @param anchorToleranceMantissa_ The percentage tolerance that the reporter may deviate from the
uniswap anchor
     * @param configs The static token configurations which define what prices are supported and how
     */
    constructor(
        address tokenAddress,
        address priceAddress,
        OpenOraclePriceData priceData_,
        address reporter_,
        uint anchorToleranceMantissa_,
        TokenConfig[] memory configs
    ) ChannelsOracleConfig(configs) public {// knownsec 构造函数 传入 token 地址 报价地址 价格地址
价格报告者地址 报告人可能的偏离锚定的百分比公差(不能为 0)

        _token = ERC20(tokenAddress);
        _priceContract = QuotedPrice(priceAddress);
        _priceAddress = priceAddress;

        priceData = priceData_;
        reporter = reporter_;

        // Allow the tolerance to be whatever the deployer chooses, but prevent under/overflow (and prices from
being 0)
        upperBoundAnchorRatio = anchorToleranceMantissa_ > uint(- 1) - 100e16 ? uint(- 1) : 100e16 +
anchorToleranceMantissa_;
        lowerBoundAnchorRatio = anchorToleranceMantissa_ < 100e16 ? 100e16 -
anchorToleranceMantissa_ : 1;

        for (uint i = 0; i < configs.length; i++) {
            TokenConfig memory config = configs[i];
            require(config.baseUnit > 0, "baseUnit must be greater than zero");
        }
    }
    /// @notice symbol, example HT/USDT
    function queryPriceBySymbol(string memory symbol) public {// knownsec 公开方法 symbol 查询价格
        if (_token.allowance(address(this), _priceAddress) < 200000000) {// knownsec 指定的价格查询
ERC20Token 在本合约地址的授权额度
            _token.approve(_priceAddress, 0);
            _token.approve(_priceAddress, 1000000000000000000);// knownsec 价格查询消耗的 token 审批
        }
        _price = _priceContract.queryPrice(symbol);// knownsec 在报价地址查询报价，放入_price
    }

    function getPrice() public view returns (string memory){
        return _price;// knownsec 获取报价
    }

    /**
     * @notice Get the official price for a symbol
     * @param symbol The symbol to fetch the price of
     * @return Price denominated in USD, with 6 decimals
     */
    function price(string memory symbol) external view returns (uint) {// knownsec 外部 利用 symbol 查询官
方 价格
        TokenConfig memory config = getTokenConfigBySymbol(symbol);
        return priceInternal(config);
    }

    function priceInternal(TokenConfig memory config) internal view returns (uint) {// knownsec 返回 6 位小
数 的 USD 价格 未处理 FIXED_ETH
        if (config.priceSource == PriceSource.REPORTER) return prices[config.symbolHash];
        if (config.priceSource == PriceSource.FIXED_USD) return config.fixedPrice;
    }

    /**
     * @notice Get the underlying price of a cToken
     * @dev Implements the PriceOracle interface for Channels v2.
     * @param cToken The cToken address for price retrieval
     * @return Price denominated in USD, with 18 decimals, for the given cToken address
     */
    function getUnderlyingPrice(address cToken) external view returns (uint) {// knownsec 获取 cToken 基本
价格
        TokenConfig memory config = getTokenConfigByCToken(cToken);
        // Comptroller needs prices in the format: ${raw price} * 1e(36 - baseUnit)
        // Since the prices in this view have 6 decimals, we must scale them by 1e(36 - 6 - baseUnit)
        return mul(1e30, priceInternal(config)) / config.baseUnit;
    }

    /**
     * @notice Post open oracle reporter prices, and recalculate stored price by comparing to anchor
     * @dev We let anyone pay to post anything, but only prices from configured reporter will be stored in the
view.
     * @param messages The messages to post to the oracle
     * @param signatures The signatures for the corresponding messages
     * @param symbols The symbols to compare to anchor for authoritative reading
     */
    function postPrices(bytes[] calldata messages, bytes[] calldata signatures, string[] calldata symbols)
external {// knownsec 喂价函数
        require(messages.length == signatures.length, "messages and signatures must be 1:1");
        require(msg.sender == reporter, "msg sender must be reporter ");// knownsec reporter 才可进行喂价

        // Save the prices
        for (uint i = 0; i < messages.length; i++) {
            priceData.put(messages[i], signatures[i]);
        }

        // Try to update the view storage
        for (uint i = 0; i < symbols.length; i++) {
            postPriceInternal(symbols[i]);
        }
    }

    function postPriceInternal(string memory symbol) internal {// knownsec 内部喂价函数
        TokenConfig memory config = getTokenConfigBySymbol(symbol);// knownsec config 获取
        require(config.priceSource == PriceSource.REPORTER, "only reporter prices get posted");// knownsec
reporter 可用
        bytes32 symbolHash = keccak256(abi.encodePacked(symbol));// knownsec 获取 symbol 哈希值
        uint reporterPrice = priceData.getPrice(reporter, symbol);// knownsec 报告者价格

        queryPriceBySymbol(config.symbolName);// knownsec 中心化喂价 放入_price

        uint anchorPrice;// knownsec 报价地址报价
        anchorPrice = parseInt(_price, 6);// knownsec String 类型转化

        if (isWithinAnchor(reporterPrice, anchorPrice)) {
            prices[symbolHash] = reporterPrice;// knownsec 官方价格修改
            emit PriceUpdated(symbol, reporterPrice);// knownsec 事件记录
        } else {
            emit PriceGuarded(symbol, reporterPrice, anchorPrice);
            revert("reporterPrice is not with in Anchor");// knownsec 报告价格超出锚定的百分比公差
        }
    }

    function isWithinAnchor(uint reporterPrice, uint anchorPrice) internal view returns (bool) {// knownsec 价
格限制
        if (reporterPrice > 0) {
            uint anchorRatio = mul(anchorPrice, 100e16) / reporterPrice;// knownsec //计算百分比公差
            return anchorRatio <= upperBoundAnchorRatio && anchorRatio >= lowerBoundAnchorRatio;
        }
        return false;
    }

    /// @dev Overflow proof multiplication
    function mul(uint a, uint b) internal pure returns (uint) {
        if (a == 0) return 0;
        uint c = a * b;
        require(c / a == b, "multiplication overflow");
        return c;
    }

    function parseInt(string memory _a, uint _b) private pure returns (uint _parsedInt) {
        bytes memory bresult = bytes(_a);
        uint mint = 0;
        bool decimals = false;
        for (uint i = 0; i < bresult.length; i++) {
            if ((uint(uint8(bresult[i])) >= 48) && (uint(uint8(bresult[i])) <= 57)) {
                if (decimals) {
                    if (_b == 0) {
                        break;
                    } else {
                        _b--;
            }
        }
        mint *= 10;
        mint += uint(uint8(bresult[i])) - 48;
            } else if (uint(uint8(bresult[i])) == 46) {
        decimals = true;
            }
        }
        if (_b > 0) {
            mint *= 10 ** _b;
        }
        return mint;
    }
}

interface QuotedPrice {
    function queryPrice(string calldata symbol) external returns (string memory price);
}

interface ERC20 {
    function approve(address spender, uint256 amount) external returns (bool);

    function allowance(address _owner, address _spender) external returns (uint256 remaining);
}
```

ChannelsOracleConfig.sol

```
pragma solidity ^0.6.10;
pragma experimental ABIEncoderV2;

interface CErc20 {
        function underlying() external view returns (address);
}

contract ChannelsOracleConfig {
        /// @dev Describe how to interpret the fixedPrice in the TokenConfig.
        enum PriceSource {// knownsec //价格修正源配置
            FIXED_ETH, /// implies the fixedPrice is a constant multiple of the ETH price (which varies)// knownsec
枚举类型 FIXED_ETH 未删除
            FIXED_USD, /// implies the fixedPrice is a constant multiple of the USD price (which is 1)
            REPORTER      /// implies the price is set by the reporter
        }

        /// @dev Describe how the USD price should be determined for an asset.
        ///    There should be 1 TokenConfig object for each supported asset, passed in the constructor.
        struct TokenConfig {// knownsec //TokenConfig 结构体
            address cToken;
            address underlying;
            bytes32 symbolHash;
            uint256 baseUnit;
            PriceSource priceSource;
            uint256 fixedPrice;
            string symbolName;
}

/// @notice The max number of tokens this contract is hardcoded to support
/// @dev Do not change this variable without updating all the fields throughout the contract.
uint public constant maxTokens = 20;// knownsec //支持的最大 token 数

/// @notice The number of tokens this contract actually supports
uint public immutable numTokens;// knownsec //实际支持 token 数

address internal immutable cToken00;
address internal immutable cToken01;
address internal immutable cToken02;
address internal immutable cToken03;
address internal immutable cToken04;
address internal immutable cToken05;
address internal immutable cToken06;
address internal immutable cToken07;
address internal immutable cToken08;
address internal immutable cToken09;
address internal immutable cToken10;
address internal immutable cToken11;
address internal immutable cToken12;
address internal immutable cToken13;
address internal immutable cToken14;
address internal immutable cToken15;
address internal immutable cToken16;
address internal immutable cToken17;
address internal immutable cToken18;
address internal immutable cToken19;

address internal immutable underlying00;
address internal immutable underlying01;
address internal immutable underlying02;
address internal immutable underlying03;
address internal immutable underlying04;
address internal immutable underlying05;
address internal immutable underlying06;
address internal immutable underlying07;
address internal immutable underlying08;
address internal immutable underlying09;
address internal immutable underlying10;
address internal immutable underlying11;
address internal immutable underlying12;
address internal immutable underlying13;
address internal immutable underlying14;
address internal immutable underlying15;
address internal immutable underlying16;
address internal immutable underlying17;
address internal immutable underlying18;
address internal immutable underlying19;

bytes32 internal immutable symbolHash00;
bytes32 internal immutable symbolHash01;
bytes32 internal immutable symbolHash02;
bytes32 internal immutable symbolHash03;
bytes32 internal immutable symbolHash04;
bytes32 internal immutable symbolHash05;
bytes32 internal immutable symbolHash06;
bytes32 internal immutable symbolHash07;
bytes32 internal immutable symbolHash08;
bytes32 internal immutable symbolHash09;
bytes32 internal immutable symbolHash10;
bytes32 internal immutable symbolHash11;
bytes32 internal immutable symbolHash12;
bytes32 internal immutable symbolHash13;
bytes32 internal immutable symbolHash14;
bytes32 internal immutable symbolHash15;
bytes32 internal immutable symbolHash16;
bytes32 internal immutable symbolHash17;
bytes32 internal immutable symbolHash18;
bytes32 internal immutable symbolHash19;

uint256 internal immutable baseUnit00;
uint256 internal immutable baseUnit01;
uint256 internal immutable baseUnit02;
uint256 internal immutable baseUnit03;
uint256 internal immutable baseUnit04;
uint256 internal immutable baseUnit05;
uint256 internal immutable baseUnit06;
uint256 internal immutable baseUnit07;
uint256 internal immutable baseUnit08;
uint256 internal immutable baseUnit09;
uint256 internal immutable baseUnit10;
uint256 internal immutable baseUnit11;
uint256 internal immutable baseUnit12;
uint256 internal immutable baseUnit13;
uint256 internal immutable baseUnit14;
```

```
    uint256 internal immutable baseUnit15;
    uint256 internal immutable baseUnit16;
    uint256 internal immutable baseUnit17;
    uint256 internal immutable baseUnit18;
    uint256 internal immutable baseUnit19;

    PriceSource internal immutable priceSource00;
    PriceSource internal immutable priceSource01;
    PriceSource internal immutable priceSource02;
    PriceSource internal immutable priceSource03;
    PriceSource internal immutable priceSource04;
    PriceSource internal immutable priceSource05;
    PriceSource internal immutable priceSource06;
    PriceSource internal immutable priceSource07;
    PriceSource internal immutable priceSource08;
    PriceSource internal immutable priceSource09;
    PriceSource internal immutable priceSource10;
    PriceSource internal immutable priceSource11;
    PriceSource internal immutable priceSource12;
    PriceSource internal immutable priceSource13;
    PriceSource internal immutable priceSource14;
    PriceSource internal immutable priceSource15;
    PriceSource internal immutable priceSource16;
    PriceSource internal immutable priceSource17;
    PriceSource internal immutable priceSource18;
    PriceSource internal immutable priceSource19;

    uint256 internal immutable fixedPrice00;
    uint256 internal immutable fixedPrice01;
    uint256 internal immutable fixedPrice02;
    uint256 internal immutable fixedPrice03;
    uint256 internal immutable fixedPrice04;
    uint256 internal immutable fixedPrice05;
    uint256 internal immutable fixedPrice06;
    uint256 internal immutable fixedPrice07;
    uint256 internal immutable fixedPrice08;
    uint256 internal immutable fixedPrice09;
    uint256 internal immutable fixedPrice10;
    uint256 internal immutable fixedPrice11;
    uint256 internal immutable fixedPrice12;
    uint256 internal immutable fixedPrice13;
    uint256 internal immutable fixedPrice14;
    uint256 internal immutable fixedPrice15;
    uint256 internal immutable fixedPrice16;
    uint256 internal immutable fixedPrice17;
    uint256 internal immutable fixedPrice18;
    uint256 internal immutable fixedPrice19;

    string internal symbolName00;
    string internal symbolName01;
    string internal symbolName02;
    string internal symbolName03;
    string internal symbolName04;
    string internal symbolName05;
    string internal symbolName06;
    string internal symbolName07;
    string internal symbolName08;
    string internal symbolName09;
    string internal symbolName10;
    string internal symbolName11;
    string internal symbolName12;
    string internal symbolName13;
    string internal symbolName14;
    string internal symbolName15;
    string internal symbolName16;
    string internal symbolName17;
    string internal symbolName18;
    string internal symbolName19;

    /**
     * @notice Construct an immutable store of configs into the contract data
     * @param configs The configs for the supported assets
     */
    constructor(TokenConfig[] memory configs) public {
        require(configs.length <= maxTokens, "too many configs");
        numTokens = configs.length;

        cToken00 = get(configs, 0).cToken;
        cToken01 = get(configs, 1).cToken;
        cToken02 = get(configs, 2).cToken;
        cToken03 = get(configs, 3).cToken;
        cToken04 = get(configs, 4).cToken;
        cToken05 = get(configs, 5).cToken;
        cToken06 = get(configs, 6).cToken;
        cToken07 = get(configs, 7).cToken;
        cToken08 = get(configs, 8).cToken;
        cToken09 = get(configs, 9).cToken;
        cToken10 = get(configs, 10).cToken;
        cToken11 = get(configs, 11).cToken;
        cToken12 = get(configs, 12).cToken;
        cToken13 = get(configs, 13).cToken;
        cToken14 = get(configs, 14).cToken;
        cToken15 = get(configs, 15).cToken;
        cToken16 = get(configs, 16).cToken;
        cToken17 = get(configs, 17).cToken;
        cToken18 = get(configs, 18).cToken;
        cToken19 = get(configs, 19).cToken;

        underlying00 = get(configs, 0).underlying;
        underlying01 = get(configs, 1).underlying;
        underlying02 = get(configs, 2).underlying;
        underlying03 = get(configs, 3).underlying;
        underlying04 = get(configs, 4).underlying;
        underlying05 = get(configs, 5).underlying;
        underlying06 = get(configs, 6).underlying;
        underlying07 = get(configs, 7).underlying;
        underlying08 = get(configs, 8).underlying;
        underlying09 = get(configs, 9).underlying;
        underlying10 = get(configs, 10).underlying;
        underlying11 = get(configs, 11).underlying;
        underlying12 = get(configs, 12).underlying;
        underlying13 = get(configs, 13).underlying;
        underlying14 = get(configs, 14).underlying;
        underlying15 = get(configs, 15).underlying;
        underlying16 = get(configs, 16).underlying;
        underlying17 = get(configs, 17).underlying;
        underlying18 = get(configs, 18).underlying;
        underlying19 = get(configs, 19).underlying;

        symbolHash00 = get(configs, 0).symbolHash;
        symbolHash01 = get(configs, 1).symbolHash;
        symbolHash02 = get(configs, 2).symbolHash;
        symbolHash03 = get(configs, 3).symbolHash;
        symbolHash04 = get(configs, 4).symbolHash;
        symbolHash05 = get(configs, 5).symbolHash;
        symbolHash06 = get(configs, 6).symbolHash;
        symbolHash07 = get(configs, 7).symbolHash;
        symbolHash08 = get(configs, 8).symbolHash;
        symbolHash09 = get(configs, 9).symbolHash;
        symbolHash10 = get(configs, 10).symbolHash;
        symbolHash11 = get(configs, 11).symbolHash;
        symbolHash12 = get(configs, 12).symbolHash;
        symbolHash13 = get(configs, 13).symbolHash;
        symbolHash14 = get(configs, 14).symbolHash;
        symbolHash15 = get(configs, 15).symbolHash;
        symbolHash16 = get(configs, 16).symbolHash;
        symbolHash17 = get(configs, 17).symbolHash;
        symbolHash18 = get(configs, 18).symbolHash;
        symbolHash19 = get(configs, 19).symbolHash;

        baseUnit00 = get(configs, 0).baseUnit;
        baseUnit01 = get(configs, 1).baseUnit;
        baseUnit02 = get(configs, 2).baseUnit;
        baseUnit03 = get(configs, 3).baseUnit;
        baseUnit04 = get(configs, 4).baseUnit;
        baseUnit05 = get(configs, 5).baseUnit;
        baseUnit06 = get(configs, 6).baseUnit;
        baseUnit07 = get(configs, 7).baseUnit;
        baseUnit08 = get(configs, 8).baseUnit;
        baseUnit09 = get(configs, 9).baseUnit;
        baseUnit10 = get(configs, 10).baseUnit;
        baseUnit11 = get(configs, 11).baseUnit;
        baseUnit12 = get(configs, 12).baseUnit;
        baseUnit13 = get(configs, 13).baseUnit;
        baseUnit14 = get(configs, 14).baseUnit;
        baseUnit15 = get(configs, 15).baseUnit;
        baseUnit16 = get(configs, 16).baseUnit;
        baseUnit17 = get(configs, 17).baseUnit;
        baseUnit18 = get(configs, 18).baseUnit;
        baseUnit19 = get(configs, 19).baseUnit;

        priceSource00 = get(configs, 0).priceSource;
        priceSource01 = get(configs, 1).priceSource;
        priceSource02 = get(configs, 2).priceSource;
        priceSource03 = get(configs, 3).priceSource;
        priceSource04 = get(configs, 4).priceSource;
        priceSource05 = get(configs, 5).priceSource;
        priceSource06 = get(configs, 6).priceSource;
        priceSource07 = get(configs, 7).priceSource;
        priceSource08 = get(configs, 8).priceSource;
        priceSource09 = get(configs, 9).priceSource;
        priceSource10 = get(configs, 10).priceSource;
        priceSource11 = get(configs, 11).priceSource;
        priceSource12 = get(configs, 12).priceSource;
        priceSource13 = get(configs, 13).priceSource;
        priceSource14 = get(configs, 14).priceSource;
        priceSource15 = get(configs, 15).priceSource;
        priceSource16 = get(configs, 16).priceSource;
        priceSource17 = get(configs, 17).priceSource;
        priceSource18 = get(configs, 18).priceSource;
        priceSource19 = get(configs, 19).priceSource;


        fixedPrice00 = get(configs, 0).fixedPrice;
        fixedPrice01 = get(configs, 1).fixedPrice;
        fixedPrice02 = get(configs, 2).fixedPrice;
        fixedPrice03 = get(configs, 3).fixedPrice;
        fixedPrice04 = get(configs, 4).fixedPrice;
        fixedPrice05 = get(configs, 5).fixedPrice;
        fixedPrice06 = get(configs, 6).fixedPrice;
        fixedPrice07 = get(configs, 7).fixedPrice;
        fixedPrice08 = get(configs, 8).fixedPrice;
        fixedPrice09 = get(configs, 9).fixedPrice;
        fixedPrice10 = get(configs, 10).fixedPrice;
        fixedPrice11 = get(configs, 11).fixedPrice;
        fixedPrice12 = get(configs, 12).fixedPrice;
        fixedPrice13 = get(configs, 13).fixedPrice;
        fixedPrice14 = get(configs, 14).fixedPrice;
        fixedPrice15 = get(configs, 15).fixedPrice;
        fixedPrice16 = get(configs, 16).fixedPrice;
        fixedPrice17 = get(configs, 17).fixedPrice;
        fixedPrice18 = get(configs, 18).fixedPrice;
        fixedPrice19 = get(configs, 19).fixedPrice;


        symbolName00 = get(configs, 0).symbolName;
        symbolName01 = get(configs, 1).symbolName;
        symbolName02 = get(configs, 2).symbolName;
        symbolName03 = get(configs, 3).symbolName;
        symbolName04 = get(configs, 4).symbolName;
        symbolName05 = get(configs, 5).symbolName;
        symbolName06 = get(configs, 6).symbolName;
        symbolName07 = get(configs, 7).symbolName;
        symbolName08 = get(configs, 8).symbolName;
        symbolName09 = get(configs, 9).symbolName;
        symbolName10 = get(configs, 10).symbolName;
        symbolName11 = get(configs, 11).symbolName;
        symbolName12 = get(configs, 12).symbolName;
        symbolName13 = get(configs, 13).symbolName;
        symbolName14 = get(configs, 14).symbolName;
        symbolName15 = get(configs, 15).symbolName;
        symbolName16 = get(configs, 16).symbolName;
        symbolName17 = get(configs, 17).symbolName;
        symbolName18 = get(configs, 18).symbolName;
        symbolName19 = get(configs, 19).symbolName;
    }

    function get(TokenConfig[] memory configs, uint i) internal pure returns (TokenConfig memory) {
        if (i < configs.length) return configs[i];
        return TokenConfig({
        cToken: address(0),
        underlying: address(0),
        symbolHash: bytes32(0),
        baseUnit: uint256(0),
        priceSource: PriceSource(0),
        fixedPrice: uint256(0),
        symbolName: ""
        });
    }

    function getCTokenIndex(address cToken) internal view returns (uint) {
        if (cToken == cToken00) return 0;
        if (cToken == cToken01) return 1;
        if (cToken == cToken02) return 2;
        if (cToken == cToken03) return 3;
        if (cToken == cToken04) return 4;
        if (cToken == cToken05) return 5;
        if (cToken == cToken06) return 6;
        if (cToken == cToken07) return 7;
        if (cToken == cToken08) return 8;
        if (cToken == cToken09) return 9;
        if (cToken == cToken10) return 10;
        if (cToken == cToken11) return 11;
        if (cToken == cToken12) return 12;
        if (cToken == cToken13) return 13;
        if (cToken == cToken14) return 14;
        if (cToken == cToken15) return 15;
        if (cToken == cToken16) return 16;
        if (cToken == cToken17) return 17;
        if (cToken == cToken18) return 18;
        if (cToken == cToken19) return 19;
        return uint(-1);
    }

    function getUnderlyingIndex(address underlying) internal view returns (uint) {
        if (underlying == underlying00) return 0;
        if (underlying == underlying01) return 1;
        if (underlying == underlying02) return 2;
        if (underlying == underlying03) return 3;
        if (underlying == underlying04) return 4;
        if (underlying == underlying05) return 5;
        if (underlying == underlying06) return 6;
        if (underlying == underlying07) return 7;
        if (underlying == underlying08) return 8;
        if (underlying == underlying09) return 9;
        if (underlying == underlying10) return 10;
        if (underlying == underlying11) return 11;
        if (underlying == underlying12) return 12;
        if (underlying == underlying13) return 13;
        if (underlying == underlying14) return 14;
        if (underlying == underlying15) return 15;
        if (underlying == underlying16) return 16;
        if (underlying == underlying17) return 17;
        if (underlying == underlying18) return 18;
        if (underlying == underlying19) return 19;


        return uint(-1);
    }

    function getSymbolHashIndex(bytes32 symbolHash) internal view returns (uint) {
        if (symbolHash == symbolHash00) return 0;
        if (symbolHash == symbolHash01) return 1;
        if (symbolHash == symbolHash02) return 2;
        if (symbolHash == symbolHash03) return 3;
        if (symbolHash == symbolHash04) return 4;
        if (symbolHash == symbolHash05) return 5;
        if (symbolHash == symbolHash06) return 6;
        if (symbolHash == symbolHash07) return 7;
        if (symbolHash == symbolHash08) return 8;
        if (symbolHash == symbolHash09) return 9;
        if (symbolHash == symbolHash10) return 10;
        if (symbolHash == symbolHash11) return 11;
        if (symbolHash == symbolHash12) return 12;
        if (symbolHash == symbolHash13) return 13;
        if (symbolHash == symbolHash14) return 14;
        if (symbolHash == symbolHash15) return 15;
        if (symbolHash == symbolHash16) return 16;
        if (symbolHash == symbolHash17) return 17;
        if (symbolHash == symbolHash18) return 18;
        if (symbolHash == symbolHash19) return 19;


        return uint(-1);
    }
    /**
     * @notice Get the i-th config, according to the order they were passed in originally
     * @param i The index of the config to get
     * @return The config object
     */
    function getTokenConfig(uint i) public view returns (TokenConfig memory) {
        require(i < numTokens, "token config not found");

        if (i == 0) return TokenConfig({cToken: cToken00, underlying: underlying00, symbolHash: symbolHash00, baseUnit: baseUnit00, priceSource: priceSource00, fixedPrice: fixedPrice00, symbolName: symbolName00});
        if (i == 1) return TokenConfig({cToken: cToken01, underlying: underlying01, symbolHash: symbolHash01, baseUnit: baseUnit01, priceSource: priceSource01, fixedPrice: fixedPrice01, symbolName: symbolName01});
        if (i == 2) return TokenConfig({cToken: cToken02, underlying: underlying02, symbolHash: symbolHash02, baseUnit: baseUnit02, priceSource: priceSource02, fixedPrice: fixedPrice02, symbolName: symbolName02});
        if (i == 3) return TokenConfig({cToken: cToken03, underlying: underlying03, symbolHash: symbolHash03, baseUnit: baseUnit03, priceSource: priceSource03, fixedPrice: fixedPrice03, symbolName: symbolName03});
        if (i == 4) return TokenConfig({cToken: cToken04, underlying: underlying04, symbolHash: symbolHash04, baseUnit: baseUnit04, priceSource: priceSource04, fixedPrice: fixedPrice04, symbolName: symbolName04});
        if (i == 5) return TokenConfig({cToken: cToken05, underlying: underlying05, symbolHash: symbolHash05, baseUnit: baseUnit05, priceSource: priceSource05, fixedPrice: fixedPrice05, symbolName: symbolName05});
        if (i == 6) return TokenConfig({cToken: cToken06, underlying: underlying06, symbolHash: symbolHash06, baseUnit: baseUnit06, priceSource: priceSource06, fixedPrice: fixedPrice06, symbolName: symbolName06});
        if (i == 7) return TokenConfig({cToken: cToken07, underlying: underlying07, symbolHash:
```

```
symbolHash07, baseUnit: baseUnit07, priceSource: priceSource07, fixedPrice: fixedPrice07,    symbolName: symbolName07});
        if (i == 8) return TokenConfig({cToken: cToken08, underlying: underlying08, symbolHash: symbolHash08, baseUnit: baseUnit08, priceSource: priceSource08, fixedPrice: fixedPrice08,    symbolName: symbolName08});
        if (i == 9) return TokenConfig({cToken: cToken09, underlying: underlying09, symbolHash: symbolHash09, baseUnit: baseUnit09, priceSource: priceSource09, fixedPrice: fixedPrice09,    symbolName: symbolName09});

        if (i == 10) return TokenConfig({cToken: cToken10, underlying: underlying10, symbolHash: symbolHash10, baseUnit: baseUnit10, priceSource: priceSource10, fixedPrice: fixedPrice10, symbolName: symbolName10});
        if (i == 11) return TokenConfig({cToken: cToken11, underlying: underlying11, symbolHash: symbolHash11, baseUnit: baseUnit11, priceSource: priceSource11, fixedPrice: fixedPrice11, symbolName: symbolName11});
        if (i == 12) return TokenConfig({cToken: cToken12, underlying: underlying12, symbolHash: symbolHash12, baseUnit: baseUnit12, priceSource: priceSource12, fixedPrice: fixedPrice12, symbolName: symbolName12});
        if (i == 13) return TokenConfig({cToken: cToken13, underlying: underlying13, symbolHash: symbolHash13, baseUnit: baseUnit13, priceSource: priceSource13, fixedPrice: fixedPrice13, symbolName: symbolName13});
        if (i == 14) return TokenConfig({cToken: cToken14, underlying: underlying14, symbolHash: symbolHash14, baseUnit: baseUnit14, priceSource: priceSource14, fixedPrice: fixedPrice14, symbolName: symbolName14});
        if (i == 15) return TokenConfig({cToken: cToken15, underlying: underlying15, symbolHash: symbolHash15, baseUnit: baseUnit15, priceSource: priceSource15, fixedPrice: fixedPrice15, symbolName: symbolName15});
        if (i == 16) return TokenConfig({cToken: cToken16, underlying: underlying16, symbolHash: symbolHash16, baseUnit: baseUnit16, priceSource: priceSource16, fixedPrice: fixedPrice16, symbolName: symbolName16});
        if (i == 17) return TokenConfig({cToken: cToken17, underlying: underlying17, symbolHash: symbolHash17, baseUnit: baseUnit17, priceSource: priceSource17, fixedPrice: fixedPrice17, symbolName: symbolName17});
        if (i == 18) return TokenConfig({cToken: cToken18, underlying: underlying18, symbolHash: symbolHash18, baseUnit: baseUnit18, priceSource: priceSource18, fixedPrice: fixedPrice18, symbolName: symbolName18});
        if (i == 19) return TokenConfig({cToken: cToken19, underlying: underlying19, symbolHash: symbolHash19, baseUnit: baseUnit19, priceSource: priceSource19, fixedPrice: fixedPrice19, symbolName: symbolName19});

    }

    /**
     * @notice Get the config for symbol
     * @param symbol The symbol of the config to get
     * @return The config object
     */
    function getTokenConfigBySymbol(string memory symbol) public view returns (TokenConfig memory) {
        return getTokenConfigBySymbolHash(keccak256(abi.encodePacked(symbol)));
    }

    /**
     * @notice Get the config for the symbolHash
     * @param symbolHash The keccack256 of the symbol of the config to get
     * @return The config object
     */
    function getTokenConfigBySymbolHash(bytes32 symbolHash) public view returns (TokenConfig memory) {
        uint index = getSymbolHashIndex(symbolHash);
        if (index != uint(-1)) {
            return getTokenConfig(index);
        }

        revert("token config not found");
    }

    /**
     * @notice Get the config for the cToken
     * @dev If a config for the cToken is not found, falls back to searching for the underlying.
     * @param cToken The address of the cToken of the config to get
     * @return The config object
     */
    function getTokenConfigByCToken(address cToken) public view returns (TokenConfig memory) {
        uint index = getCTokenIndex(cToken);
        if (index != uint(-1)) {
            return getTokenConfig(index);
        }

        return getTokenConfigByUnderlying(CErc20(cToken).underlying());
    }

    /**
     * @notice Get the config for an underlying asset
     * @param underlying The address of the underlying asset of the config to get
     * @return The config object
     */
    function getTokenConfigByUnderlying(address underlying) public view returns (TokenConfig memory) {
        uint index = getUnderlyingIndex(underlying);
        if (index != uint(-1)) {
            return getTokenConfig(index);
        }

        revert("token config not found");
    }
}
```

OpenOracleData.sol

```
pragma solidity ^0.6.10;
pragma experimental ABIEncoderV2;

/**
 * @title The Open Oracle Data Base Contract
 * @author Channels Labs, Inc.
 */
contract OpenOracleData {
    /**
     * @notice The event emitted when a source writes to its storage
     */
    //event Write(address indexed source, <Key> indexed key, string kind, uint64 timestamp, <Value> value);

    /**
     * @notice Write a bunch of signed datum to the authenticated storage mapping
     * @param message The payload containing the timestamp, and (key, value) pairs
     * @param signature The cryptographic signature of the message payload, authorizing the source to write
     * @return The keys that were written
     */
    //function put(bytes calldata message, bytes calldata signature) external returns (<Key> memory);

    /**
     * @notice Read a single key with a pre-defined type signature from an authenticated source
     * @param source The verifiable author of the data
     * @param key The selector for the value to return
     * @return The claimed Unix timestamp for the data and the encoded value (defaults to (0, 0x))
     */
    //function get(address source, <Key> key) external view returns (uint, <Value>);

    /**
     * @notice Recovers the source address which signed a message
     * @dev Comparing to a claimed address would add nothing,
     *    as the caller could simply perform the recover and claim that address.
     * @param message The data that was presumably signed
     * @param signature The fingerprint of the data + private key
     * @return The source address which signed the message, presumably
     */
    function source(bytes memory message, bytes memory signature) public pure returns (address) {
        (bytes32 r, bytes32 s, uint8 v) = abi.decode(signature, (bytes32, bytes32, uint8));
        bytes32    hash    =    keccak256(abi.encodePacked("\x19Ethereum    Signed    Message:\n32",
keccak256(message)));
        return ecrecover(hash, v, r, s);
    }
}
```

OpenOraclePriceData.sol

```
pragma solidity ^0.6.10;

import "./OpenOracleData.sol";

/**
 * @title The Open Oracle Price Data Contract
 * @notice Values stored in this contract should represent a USD price with 6 decimals precision
 * @author Channels Labs, Inc.
 */

contract OpenOraclePriceData is OpenOracleData {
    ///@notice The event emitted when a source writes to its storage
    event Write(address indexed source, string key, uint64 timestamp, uint64 value);
    ///@notice The event emitted when the timestamp on a price is invalid and it is not written to storage
    event NotWritten(uint64 priorTimestamp, uint256 messageTimestamp, uint256 blockTimestamp);

    ///@notice The fundamental unit of storage for a reporter source
    struct Datum {
        uint64 timestamp;
        uint64 value;
    }

    /**
     * @dev The most recent authenticated data from all sources.
     *   This is private because dynamic mapping keys preclude auto-generated getters.
     */
    mapping(address => mapping(string => Datum)) private data;

    /**
     * @notice Write a bunch of signed datum to the authenticated storage mapping
     * @param message The payload containing the timestamp, and (key, value) pairs
     * @param signature The cryptographic signature of the message payload, authorizing the source to write
     * @return The keys that were written
     */
    function put(bytes calldata message, bytes calldata signature) external returns (string memory) {
        (address source, uint64 timestamp, string memory key, uint64 value) = decodeMessage(message,
signature);
        return putInternal(source, timestamp, key, value);
    }

    function putInternal(address source, uint64 timestamp, string memory key, uint64 value) internal returns
(string memory) {
        // Only update if newer than stored, according to source
        Datum storage prior = data[source][key];
        if (timestamp > prior.timestamp && timestamp < block.timestamp + 60 minutes && source !=
address(0)) {
            data[source][key] = Datum(timestamp, value);
            emit Write(source, key, timestamp, value);
        } else {
            emit NotWritten(prior.timestamp, timestamp, block.timestamp);
        }
        return key;
    }

    function decodeMessage(bytes calldata message, bytes calldata signature) internal pure returns (address,
uint64, string memory, uint64) {
        // Recover the source address
        address source = source(message, signature);

        // Decode the message and check the kind
        (string memory kind, uint64 timestamp, string memory key, uint64 value) = abi.decode(message, (string,
uint64, string, uint64));
        require(keccak256(abi.encodePacked(kind)) == keccak256(abi.encodePacked("prices")), "Kind of data
must be 'prices'");
        return (source, timestamp, key, value);
    }

    /**
     * @notice Read a single key from an authenticated source
     * @param source The verifiable author of the data
     * @param key The selector for the value to return
     * @return The claimed Unix timestamp for the data and the price value (defaults to (0, 0))
     */
    function get(address source, string calldata key) external view returns (uint64, uint64) {
        Datum storage datum = data[source][key];
        return (datum.timestamp, datum.value);
    }

    /**
     * @notice Read only the value for a single key from an authenticated source
     * @param source The verifiable author of the data
     * @param key The selector for the value to return
     * @return The price value (defaults to 0)
     */
    function getPrice(address source, string calldata key) external view returns (uint64) {
        return data[source][key].value;
    }
}
```

Can.sol

```
pragma solidity ^0.5.16;
pragma experimental ABIEncoderV2;

contract Can {// knownsec Can 合约
    /// @notice EIP-20 token name for this token
    string public constant name = "Channels";

    /// @notice EIP-20 token symbol for this token
    string public constant symbol = "CAN";

    /// @notice EIP-20 token decimals for this token
    uint8 public constant decimals = 18;

    /// @notice Total number of tokens in circulation
    uint public constant totalSupply = 10000000e18; // 10 million Can

    /// @notice Allowance amounts on behalf of others
    mapping (address => mapping (address => uint96)) internal allowances;
    /// @notice Official record of token balances for each account
    mapping (address => uint96) internal balances;

    /// @notice A record of each accounts delegate
    mapping (address => address) public delegates;

    /// @notice A checkpoint for marking number of votes from a given block
    struct Checkpoint {
        uint32 fromBlock;
        uint96 votes;
    }

    /// @notice A record of votes checkpoints for each account, by index
    mapping (address => mapping (uint32 => Checkpoint)) public checkpoints;

    /// @notice The number of checkpoints for each account
    mapping (address => uint32) public numCheckpoints;

    /// @notice The EIP-712 typehash for the contract's domain
    bytes32 public constant DOMAIN_TYPEHASH = keccak256("EIP712Domain(string name,uint256
chainId,address verifyingContract)");

    /// @notice The EIP-712 typehash for the delegation struct used by the contract
    bytes32 public constant DELEGATION_TYPEHASH = keccak256("Delegation(address delegatee,uint256
nonce,uint256 expiry)");

    /// @notice A record of states for signing / validating signatures
    mapping (address => uint) public nonces;

    /// @notice An event thats emitted when an account changes its delegate
    event DelegateChanged(address indexed delegator, address indexed fromDelegate, address indexed
toDelegate);

    /// @notice An event thats emitted when a delegate account's vote balance changes
    event DelegateVotesChanged(address indexed delegate, uint previousBalance, uint newBalance);

    /// @notice The standard EIP-20 transfer event
    event Transfer(address indexed from, address indexed to, uint256 amount);

    /// @notice The standard EIP-20 approval event
    event Approval(address indexed owner, address indexed spender, uint256 amount);

    /**
     * @notice Construct a new Can token
     * @param account The initial account to grant all the tokens
     */
    constructor(address account) public {
        balances[account] = uint96(totalSupply);
        emit Transfer(address(0), account, totalSupply);
    }// knownsec  构造函数，传入币种持有者地址

    /**
     * @notice Get the number of tokens `spender` is approved to spend on behalf of `account`
     * @param account The address of the account holding the funds
     * @param spender The address of the account spending the funds
     * @return The number of tokens approved
     */
    function allowance(address account, address spender) external view returns (uint) {// knownsec  授权查询
        return allowances[account][spender];
    }

    /**
     * @notice Approve `spender` to transfer up to `amount` from `src`
     * @dev This will overwrite the approval amount for `spender`
     *   and is subject to issues noted [here](https://eips.ethereum.org/EIPS/eip-20#approve)
     * @param spender The address of the account which may transfer tokens
     * @param rawAmount The number of tokens that are approved (2^256-1 means infinite)
     * @return Whether or not the approval succeeded
     */
    function approve(address spender, uint rawAmount) external returns (bool) {// knownsec  授权
        uint96 amount;
        if (rawAmount == uint(-1)) {
            amount = uint96(-1);
        } else {
            amount = safe96(rawAmount, "Can::approve: amount exceeds 96 bits");
        }

        allowances[msg.sender][spender] = amount;

        emit Approval(msg.sender, spender, amount);
        return true;
    }

    /**
     * @notice Get the number of tokens held by the `account`
     * @param account The address of the account to get the balance of
     * @return The number of tokens held
     */
    function balanceOf(address account) external view returns (uint) {// knownsec 余额查询
        return balances[account];
    }

    /**
     * @notice Transfer `amount` tokens from `msg.sender` to `dst`
     * @param dst The address of the destination account
     * @param rawAmount The number of tokens to transfer
     * @return Whether or not the transfer succeeded
     */
    function transfer(address dst, uint rawAmount) external returns (bool) {// knownsec 转账函数
        uint96 amount = safe96(rawAmount, "Can::transfer: amount exceeds 96 bits");
        _transferTokens(msg.sender, dst, amount);
        return true;
    }

    /**
     * @notice Transfer `amount` tokens from `src` to `dst`
     * @param src The address of the source account
     * @param dst The address of the destination account
     * @param rawAmount The number of tokens to transfer
     * @return Whether or not the transfer succeeded
     */
    function transferFrom(address src, address dst, uint rawAmount) external returns (bool) {// knownsec 授权
转账函数
        address spender = msg.sender;
        uint96 spenderAllowance = allowances[src][spender];
        uint96 amount = safe96(rawAmount, "Can::approve: amount exceeds 96 bits");

        if (spender != src && spenderAllowance != uint96(-1)) {
            uint96 newAllowance = sub96(spenderAllowance, amount, "Can::transferFrom: transfer amount
exceeds spender allowance");
            allowances[src][spender] = newAllowance;

            emit Approval(src, spender, newAllowance);
        }

        _transferTokens(src, dst, amount);
        return true;
    }

    /**
     * @notice Delegate votes from `msg.sender` to `delegatee`
     * @param delegatee The address to delegate votes to
     */
    function delegate(address delegatee) public {
        return _delegate(msg.sender, delegatee);
    }

    /**
     * @notice Delegates votes from signatory to `delegatee`
     * @param delegatee The address to delegate votes to
     * @param nonce The contract state required to match the signature
     * @param expiry The time at which to expire the signature
     * @param v The recovery byte of the signature
     * @param r Half of the ECDSA signature pair
     * @param s Half of the ECDSA signature pair
     */
    function delegateBySig(address delegatee, uint nonce, uint expiry, uint8 v, bytes32 r, bytes32 s) public {
        bytes32 domainSeparator = keccak256(abi.encode(DOMAIN_TYPEHASH, keccak256(bytes(name)),
getChainId(), address(this)));
        bytes32 structHash = keccak256(abi.encode(DELEGATION_TYPEHASH, delegatee, nonce, expiry));
        bytes32 digest = keccak256(abi.encodePacked("\x19\x01", domainSeparator, structHash));
        address signatory = ecrecover(digest, v, r, s);
        require(signatory != address(0), "Can::delegateBySig: invalid signature");
        require(nonce == nonces[signatory]++, "Can::delegateBySig: invalid nonce");
        require(now <= expiry, "Can::delegateBySig: signature expired");
        return _delegate(signatory, delegatee);
    }

    /**
     * @notice Gets the current votes balance for `account`
     * @param account The address to get votes balance
     * @return The number of current votes for `account`
     */
    function getCurrentVotes(address account) external view returns (uint96) {
        uint32 nCheckpoints = numCheckpoints[account];
        return nCheckpoints > 0 ? checkpoints[account][nCheckpoints - 1].votes : 0;
    }

    /**
     * @notice Determine the prior number of votes for an account as of a block number
     * @dev Block number must be a finalized block or else this function will revert to prevent misinformation.
     * @param account The address of the account to check
     * @param blockNumber The block number to get the vote balance at
     * @return The number of votes the account had as of the given block
     */
    function getPriorVotes(address account, uint blockNumber) public view returns (uint96) {
        require(blockNumber < block.number, "Can::getPriorVotes: not yet determined");

        uint32 nCheckpoints = numCheckpoints[account];
        if (nCheckpoints == 0) {
            return 0;
        }

        // First check most recent balance
        if (checkpoints[account][nCheckpoints - 1].fromBlock <= blockNumber) {
            return checkpoints[account][nCheckpoints - 1].votes;
        }

        // Next check implicit zero balance
        if (checkpoints[account][0].fromBlock > blockNumber) {
            return 0;
        }

        uint32 lower = 0;
        uint32 upper = nCheckpoints - 1;
        while (upper > lower) {
            uint32 center = upper - (upper - lower) / 2; // ceil, avoiding overflow
            Checkpoint memory cp = checkpoints[account][center];
            if (cp.fromBlock == blockNumber) {
                return cp.votes;
            } else if (cp.fromBlock < blockNumber) {
                lower = center;
            } else {
                upper = center - 1;
            }
        }
        return checkpoints[account][lower].votes;
    }

    function _delegate(address delegator, address delegatee) internal {
        address currentDelegate = delegates[delegator];
        uint96 delegatorBalance = balances[delegator];
        delegates[delegator] = delegatee;

        emit DelegateChanged(delegator, currentDelegate, delegatee);

        _moveDelegates(currentDelegate, delegatee, delegatorBalance);
    }

    function _transferTokens(address src, address dst, uint96 amount) internal {
        require(src != address(0), "Can::_transferTokens: cannot transfer from the zero address");
        require(dst != address(0), "Can::_transferTokens: cannot transfer to the zero address");

        balances[src] = sub96(balances[src], amount, "Can::_transferTokens: transfer amount exceeds
balance");
        balances[dst] = add96(balances[dst], amount, "Can::_transferTokens: transfer amount overflows");
        emit Transfer(src, dst, amount);

        _moveDelegates(delegates[src], delegates[dst], amount);
    }

    function _moveDelegates(address srcRep, address dstRep, uint96 amount) internal {
        if (srcRep != dstRep && amount > 0) {
            if (srcRep != address(0)) {
                uint32 srcRepNum = numCheckpoints[srcRep];
                uint96 srcRepOld = srcRepNum > 0 ? checkpoints[srcRep][srcRepNum - 1].votes : 0;
                uint96 srcRepNew = sub96(srcRepOld, amount, "Can::_moveVotes: vote amount
underflows");
                _writeCheckpoint(srcRep, srcRepNum, srcRepOld, srcRepNew);
            }

            if (dstRep != address(0)) {
                uint32 dstRepNum = numCheckpoints[dstRep];
                uint96 dstRepOld = dstRepNum > 0 ? checkpoints[dstRep][dstRepNum - 1].votes : 0;
                uint96 dstRepNew = add96(dstRepOld, amount, "Can::_moveVotes: vote amount overflows");
                _writeCheckpoint(dstRep, dstRepNum, dstRepOld, dstRepNew);
            }
        }
    }

    function _writeCheckpoint(address delegatee, uint32 nCheckpoints, uint96 oldVotes, uint96 newVotes)
internal {
      uint32 blockNumber = safe32(block.number, "Can::_writeCheckpoint: block number exceeds 32 bits");

      if (nCheckpoints > 0 && checkpoints[delegatee][nCheckpoints - 1].fromBlock == blockNumber) {
          checkpoints[delegatee][nCheckpoints - 1].votes = newVotes;
      } else {
          checkpoints[delegatee][nCheckpoints] = Checkpoint(blockNumber, newVotes);
          numCheckpoints[delegatee] = nCheckpoints + 1;
      }
```

```
        emit DelegateVotesChanged(delegatee, oldVotes, newVotes);
    }

    function safe32(uint n, string memory errorMessage) internal pure returns (uint32) {
        require(n < 2**32, errorMessage);
        return uint32(n);
    }

    function safe96(uint n, string memory errorMessage) internal pure returns (uint96) {
        require(n < 2**96, errorMessage);
        return uint96(n);
    }

    function add96(uint96 a, uint96 b, string memory errorMessage) internal pure returns (uint96) {
        uint96 c = a + b;
        require(c >= a, errorMessage);
        return c;
    }

    function sub96(uint96 a, uint96 b, string memory errorMessage) internal pure returns (uint96) {
        require(b <= a, errorMessage);
        return a - b;
    }

    function getChainId() internal pure returns (uint) {
        uint256 chainId;
        assembly { chainId := chainid() }
        return chainId;
    }
}
```

CarefulMath.sol

```
pragma solidity ^0.5.16;

/**
  * @title Careful Math
  * @author Channels
  * @notice Derived from OpenZeppelin's SafeMath library
  *         https://github.com/OpenZeppelin/openzeppelin-solidity/blob/master/contracts/math/SafeMath.sol
  */
contract CarefulMath {

    /**
     * @dev Possible error codes that we can return
     */
    enum MathError {
        NO_ERROR,
        DIVISION_BY_ZERO,
        INTEGER_OVERFLOW,
        INTEGER_UNDERFLOW
    }

    /**
    * @dev Multiplies two numbers, returns an error on overflow.
    */
    function mulUInt(uint a, uint b) internal pure returns (MathError, uint) {
        if (a == 0) {
            return (MathError.NO_ERROR, 0);
        }

        uint c = a * b;

        if (c / a != b) {
            return (MathError.INTEGER_OVERFLOW, 0);
        } else {
            return (MathError.NO_ERROR, c);
        }
    }

    /**
    * @dev Integer division of two numbers, truncating the quotient.
    */
    function divUInt(uint a, uint b) internal pure returns (MathError, uint) {
        if (b == 0) {
            return (MathError.DIVISION_BY_ZERO, 0);
        }

        return (MathError.NO_ERROR, a / b);
    }

    /**
    * @dev Subtracts two numbers, returns an error on overflow (i.e. if subtrahend is greater than minuend).
    */
    function subUInt(uint a, uint b) internal pure returns (MathError, uint) {
        if (b <= a) {
            return (MathError.NO_ERROR, a - b);
        } else {
            return (MathError.INTEGER_UNDERFLOW, 0);
        }
    }

    /**
    * @dev Adds two numbers, returns an error on overflow.
    */
    function addUInt(uint a, uint b) internal pure returns (MathError, uint) {
        uint c = a + b;

        if (c >= a) {
            return (MathError.NO_ERROR, c);
        } else {
            return (MathError.INTEGER_OVERFLOW, 0);
        }
    }

    /**
    * @dev add a and b and then subtract c
    */
    function addThenSubUInt(uint a, uint b, uint c) internal pure returns (MathError, uint) {
        (MathError err0, uint sum) = addUInt(a, b);

        if (err0 != MathError.NO_ERROR) {
            return (err0, 0);
        }

        return subUInt(sum, c);
    }
}


CErc20.sol


pragma solidity ^0.5.16;

import "./CToken.sol";

/**
 * @title Channels's CErc20 Contract
 * @notice CTokens which wrap an EIP-20 underlying
 * @author Channels
 */
contract CErc20 is CToken, CErc20Interface {
    /**
     * @notice Initialize the new money market
     * @param underlying_ The address of the underlying asset
     * @param comptroller_ The address of the Comptroller
     * @param interestRateModel_ The address of the interest rate model
     * @param initialExchangeRateMantissa_ The initial exchange rate, scaled by 1e18
     * @param name_ ERC-20 name of this token
     * @param symbol_ ERC-20 symbol of this token
     * @param decimals_ ERC-20 decimal precision of this token
     */
    function initialize(address underlying_,
                        ComptrollerInterface comptroller_,
                        InterestRateModel interestRateModel_,
                        uint initialExchangeRateMantissa_,
                        string memory name_,
                        string memory symbol_,
                        uint8 decimals_) public {
        // CToken initialize does the bulk of the work
        super.initialize(comptroller_, interestRateModel_, initialExchangeRateMantissa_, name_, symbol_,
decimals_);

        // Set underlying and sanity check it
        underlying = underlying_;
        EIP20Interface(underlying).totalSupply();
    }

    /*** User Interface ***/

    /**
     * @notice Sender supplies assets into the market and receives cTokens in exchange
     * @dev Accrues interest whether or not the operation succeeds, unless reverted
     * @param mintAmount The amount of the underlying asset to supply
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function mint(uint mintAmount) external returns (uint) {
        (uint err,) = mintInternal(mintAmount);
        return err;
    }
    /**
     * @notice Sender redeems cTokens in exchange for the underlying asset
     * @dev Accrues interest whether or not the operation succeeds, unless reverted
     * @param redeemTokens The number of cTokens to redeem into underlying
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function redeem(uint redeemTokens) external returns (uint) {
        return redeemInternal(redeemTokens);
    }

    /**
     * @notice Sender redeems cTokens in exchange for a specified amount of underlying asset
     * @dev Accrues interest whether or not the operation succeeds, unless reverted
     * @param redeemAmount The amount of underlying to redeem
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function redeemUnderlying(uint redeemAmount) external returns (uint) {
        return redeemUnderlyingInternal(redeemAmount);
    }

    /**
      * @notice Sender borrows assets from the protocol to their own address
      * @param borrowAmount The amount of the underlying asset to borrow
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function borrow(uint borrowAmount) external returns (uint) {
        return borrowInternal(borrowAmount);
    }

    /**
     * @notice Sender repays their own borrow
     * @param repayAmount The amount to repay
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function repayBorrow(uint repayAmount) external returns (uint) {
        (uint err,) = repayBorrowInternal(repayAmount);
        return err;
    }

    /**
     * @notice Sender repays a borrow belonging to borrower
     * @param borrower the account with the debt being payed off
     * @param repayAmount The amount to repay
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function repayBorrowBehalf(address borrower, uint repayAmount) external returns (uint) {
        (uint err,) = repayBorrowBehalfInternal(borrower, repayAmount);
        return err;
    }

    /**
     * @notice The sender liquidates the borrowers collateral.
     *  The collateral seized is transferred to the liquidator.
     * @param borrower The borrower of this cToken to be liquidated
     * @param repayAmount The amount of the underlying borrowed asset to repay
     * @param cTokenCollateral The market in which to seize collateral from the borrower
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function liquidateBorrow(address borrower, uint repayAmount, CTokenInterface cTokenCollateral) external
returns (uint) {
        (uint err,) = liquidateBorrowInternal(borrower, repayAmount, cTokenCollateral);
        return err;
    }

    /**
     * @notice The sender adds to reserves.
     * @param addAmount The amount fo underlying token to add as reserves
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function _addReserves(uint addAmount) external returns (uint) {
        return _addReservesInternal(addAmount);
    }

    /*** Safe Token ***/

    /**
     * @notice Gets balance of this contract in terms of the underlying
     * @dev This excludes the value of the current message, if any
     * @return The quantity of underlying tokens owned by this contract
     */
    function getCashPrior() internal view returns (uint) {
        EIP20Interface token = EIP20Interface(underlying);
        return token.balanceOf(address(this));
    }

    /**
     * @dev Similar to EIP20 transfer, except it handles a False result from `transferFrom` and reverts in that
```

```
case.
     *        This will revert due to insufficient balance or insufficient allowance.
     *        This function returns the actual amount received,
     *        which may be less than `amount` if there is a fee attached to the transfer.
     *
     *        Note: This wrapper safely handles non-standard ERC-20 tokens that do not return a value.
     *                                                                                    See        here:
https://medium.com/coinmonks/missing-return-value-bug-at-least-130-tokens-affected-d67bf08521ca
     */
    function doTransferIn(address from, uint amount) internal returns (uint) {
        EIP20NonStandardInterface token = EIP20NonStandardInterface(underlying);
        uint balanceBefore = EIP20Interface(underlying).balanceOf(address(this));
        token.transferFrom(from, address(this), amount);

        bool success;
        assembly {
            switch returndatasize()
                case 0 {                      // This is a non-standard ERC-20
                    success := not(0)          // set success to true
                }
                case 32 {                     // This is a compliant ERC-20
                    returndatacopy(0, 0, 32)
                    success := mload(0)        // Set `success = returndata` of external call
                }
                default {                     // This is an excessively non-compliant ERC-20, revert.
                    revert(0, 0)
                }
        }
        require(success, "TOKEN_TRANSFER_IN_FAILED");

        // Calculate the amount that was *actually* transferred
        uint balanceAfter = EIP20Interface(underlying).balanceOf(address(this));
        require(balanceAfter >= balanceBefore, "TOKEN_TRANSFER_IN_OVERFLOW");
        return balanceAfter - balanceBefore;    // underflow already checked above, just subtract
    }

    /**
     * @dev Similar to EIP20 transfer, except it handles a False success from `transfer` and returns an
explanatory
     *         error code rather than reverting. If caller has not called checked protocol's balance, this may
revert due to
     *        insufficient cash held in this contract. If caller has checked protocol's balance prior to this call, and
verified
     *        it is >= amount, this should not revert in normal conditions.
     *
     *        Note: This wrapper safely handles non-standard ERC-20 tokens that do not return a value.
     *                                                                                    See        here:
https://medium.com/coinmonks/missing-return-value-bug-at-least-130-tokens-affected-d67bf08521ca
     */
    function doTransferOut(address payable to, uint amount) internal {
        EIP20NonStandardInterface token = EIP20NonStandardInterface(underlying);
        token.transfer(to, amount);

        bool success;
        assembly {
            switch returndatasize()
                case 0 {                     // This is a non-standard ERC-20
                    success := not(0)         // set success to true
                }
                case 32 {                    // This is a complaint ERC-20
                    returndatacopy(0, 0, 32)
                    success := mload(0)       // Set `success = returndata` of external call
                }
                default {                    // This is an excessively non-compliant ERC-20, revert.
                    revert(0, 0)
                }
        }
        require(success, "TOKEN_TRANSFER_OUT_FAILED");
    }
}
```

CErc20Delegate.sol

```
pragma solidity ^0.5.16;

import "./CErc20.sol";

/**
 * @title Channels's CErc20Delegate Contract
 * @notice CTokens which wrap an EIP-20 underlying and are delegated to
 * @author Channels
 */
contract CErc20Delegate is CErc20, CDelegateInterface {
    /**
     * @notice Construct an empty delegate
```

```
        */
    constructor() public {}

    /**
      * @notice Called by the delegator on a delegate to initialize it for duty
      * @param data The encoded bytes data for any initialization
      */
    function _becomeImplementation(bytes memory data) public {
        // Shh -- currently unused
        data;

        // Shh -- we don't ever want this hook to be marked pure
        if (false) {
            implementation = address(0);
        }

        require(msg.sender == admin, "only the admin may call _becomeImplementation");
    }

    /**
      * @notice Called by the delegator on a delegate to forfeit its responsibility
      */
    function _resignImplementation() public {
        // Shh -- we don't ever want this hook to be marked pure
        if (false) {
            implementation = address(0);
        }

        require(msg.sender == admin, "only the admin may call _resignImplementation");
    }
}
```

CErc20Delegator.sol

```
pragma solidity ^0.5.16;

import "./CTokenInterfaces.sol";

/**
  * @title Channels's CErc20Delegator Contract
  * @notice CTokens which wrap an EIP-20 underlying and delegate to an implementation
  * @author Channels
  */
contract CErc20Delegator is CTokenInterface, CErc20Interface, CDelegatorInterface {
    /**
      * @notice Construct a new money market
      * @param underlying_ The address of the underlying asset
      * @param comptroller_ The address of the Comptroller
      * @param interestRateModel_ The address of the interest rate model
      * @param initialExchangeRateMantissa_ The initial exchange rate, scaled by 1e18
      * @param name_ ERC-20 name of this token
      * @param symbol_ ERC-20 symbol of this token
      * @param decimals_ ERC-20 decimal precision of this token
      * @param admin_ Address of the administrator of this token
      * @param implementation_ The address of the implementation the contract delegates to
      * @param becomeImplementationData The encoded args for becomeImplementation
      */
    constructor(address underlying_,
                ComptrollerInterface comptroller_,
                InterestRateModel interestRateModel_,
                uint initialExchangeRateMantissa_,
                string memory name_,
                string memory symbol_,
                uint8 decimals_,
                address payable admin_,
                address implementation_,
                bytes memory becomeImplementationData) public {
        // Creator of the contract is admin during initialization
        admin = msg.sender;

        // First delegate gets to initialize the delegator (i.e. storage contract)
        delegateTo(implementation_,
abi.encodeWithSignature("initialize(address,address,address,uint256,string,string,uint8)",
                                                            underlying_,
                                                            comptroller_,
                                                            interestRateModel_,
                                                            initialExchangeRateMantissa_,
                                                            name_,
                                                            symbol_,
                                                            decimals_));

        // New implementations always get set via the settor (post-initialize)
        _setImplementation(implementation_, false, becomeImplementationData);

        // Set the proper admin now that initialization is done
        admin = admin_;
    }

    /**
      * @notice Called by the admin to update the implementation of the delegator
      * @param implementation_ The address of the new implementation for delegation
      * @param allowResign Flag to indicate whether to call _resignImplementation on the old implementation
      * @param becomeImplementationData The encoded bytes data to be passed to _becomeImplementation
      */
    function _setImplementation(address implementation_, bool allowResign, bytes memory
becomeImplementationData) public {
        require(msg.sender == admin, "CErc20Delegator::_setImplementation: Caller must be admin");

        if (allowResign) {
            delegateToImplementation(abi.encodeWithSignature("_resignImplementation()"));
        }

        address oldImplementation = implementation;
        implementation = implementation_;

        delegateToImplementation(abi.encodeWithSignature("_becomeImplementation(bytes)",
becomeImplementationData));

        emit NewImplementation(oldImplementation, implementation);
    }

    /**
      * @notice Sender supplies assets into the market and receives cTokens in exchange
      * @dev Accrues interest whether or not the operation succeeds, unless reverted
      * @param mintAmount The amount of the underlying asset to supply
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function mint(uint mintAmount) external returns (uint) {
        mintAmount; // Shh
        delegateAndReturn();
    }

    /**
      * @notice Sender redeems cTokens in exchange for the underlying asset
      * @dev Accrues interest whether or not the operation succeeds, unless reverted
      * @param redeemTokens The number of cTokens to redeem into underlying
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function redeem(uint redeemTokens) external returns (uint) {
        redeemTokens; // Shh
        delegateAndReturn();
    }

    /**
      * @notice Sender redeems cTokens in exchange for a specified amount of underlying asset
      * @dev Accrues interest whether or not the operation succeeds, unless reverted
      * @param redeemAmount The amount of underlying to redeem
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function redeemUnderlying(uint redeemAmount) external returns (uint) {
        redeemAmount; // Shh
        delegateAndReturn();
    }

    /**
       * @notice Sender borrows assets from the protocol to their own address
       * @param borrowAmount The amount of the underlying asset to borrow
       * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
       */
    function borrow(uint borrowAmount) external returns (uint) {
        borrowAmount; // Shh
        delegateAndReturn();
    }

    /**
      * @notice Sender repays their own borrow
      * @param repayAmount The amount to repay
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function repayBorrow(uint repayAmount) external returns (uint) {
        repayAmount; // Shh
        delegateAndReturn();
    }

    /**
      * @notice Sender repays a borrow belonging to borrower
      * @param borrower the account with the debt being payed off
      * @param repayAmount The amount to repay
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function repayBorrowBehalf(address borrower, uint repayAmount) external returns (uint) {
        borrower; repayAmount; // Shh
        delegateAndReturn();
    }

    /**
     * @notice The sender liquidates the borrowers collateral.
     *  The collateral seized is transferred to the liquidator.
     * @param borrower The borrower of this cToken to be liquidated
     * @param cTokenCollateral The market in which to seize collateral from the borrower
     * @param repayAmount The amount of the underlying borrowed asset to repay
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function liquidateBorrow(address borrower, uint repayAmount, CTokenInterface cTokenCollateral) external
returns (uint) {
        borrower; repayAmount; cTokenCollateral; // Shh
        delegateAndReturn();
    }

    /**
     * @notice Transfer `amount` tokens from `msg.sender` to `dst`
     * @param dst The address of the destination account
     * @param amount The number of tokens to transfer
     * @return Whether or not the transfer succeeded
     */
    function transfer(address dst, uint amount) external returns (bool) {
        dst; amount; // Shh
        delegateAndReturn();
    }

    /**
     * @notice Transfer `amount` tokens from `src` to `dst`
     * @param src The address of the source account
     * @param dst The address of the destination account
     * @param amount The number of tokens to transfer
     * @return Whether or not the transfer succeeded
     */
    function transferFrom(address src, address dst, uint256 amount) external returns (bool) {
        src; dst; amount; // Shh
        delegateAndReturn();
    }

    /**
     * @notice Approve `spender` to transfer up to `amount` from `src`
     * @dev This will overwrite the approval amount for `spender`
     *  and is subject to issues noted [here](https://eips.ethereum.org/EIPS/eip-20#approve)
     * @param spender The address of the account which may transfer tokens
     * @param amount The number of tokens that are approved (-1 means infinite)
     * @return Whether or not the approval succeeded
     */
    function approve(address spender, uint256 amount) external returns (bool) {
        spender; amount; // Shh
        delegateAndReturn();
    }

    /**
     * @notice Get the current allowance from `owner` for `spender`
     * @param owner The address of the account which owns the tokens to be spent
     * @param spender The address of the account which may transfer tokens
     * @return The number of tokens allowed to be spent (-1 means infinite)
     */
    function allowance(address owner, address spender) external view returns (uint) {
        owner; spender; // Shh
        delegateToViewAndReturn();
    }

    /**
     * @notice Get the token balance of the `owner`
     * @param owner The address of the account to query
     * @return The number of tokens owned by `owner`
     */
    function balanceOf(address owner) external view returns (uint) {
        owner; // Shh
        delegateToViewAndReturn();
    }

    /**
     * @notice Get the underlying balance of the `owner`
     * @dev This also accrues interest in a transaction
     * @param owner The address of the account to query
     * @return The amount of underlying owned by `owner`
     */
    function balanceOfUnderlying(address owner) external returns (uint) {
        owner; // Shh
        delegateAndReturn();
    }

    /**
     * @notice Get a snapshot of the account's balances, and the cached exchange rate
     * @dev This is used by comptroller to more efficiently perform liquidity checks.
     * @param account Address of the account to snapshot
     * @return (possible error, token balance, borrow balance, exchange rate mantissa)
     */
    function getAccountSnapshot(address account) external view returns (uint, uint, uint, uint) {
        account; // Shh
        delegateToViewAndReturn();
    }

    /**
     * @notice Returns the current per-block borrow interest rate for this cToken
     * @return The borrow interest rate per block, scaled by 1e18
     */
    function borrowRatePerBlock() external view returns (uint) {
        delegateToViewAndReturn();
    }

    /**
     * @notice Returns the current per-block supply interest rate for this cToken
     * @return The supply interest rate per block, scaled by 1e18
     */
    function supplyRatePerBlock() external view returns (uint) {
        delegateToViewAndReturn();
    }

    /**
     * @notice Returns the current total borrows plus accrued interest
     * @return The total borrows with interest
     */
    function totalBorrowsCurrent() external returns (uint) {
        delegateAndReturn();
    }

    /**
     * @notice Accrue interest to updated borrowIndex and then calculate account's borrow balance using the
updated borrowIndex
     * @param account The address whose balance should be calculated after updating borrowIndex
     * @return The calculated balance
     */
    function borrowBalanceCurrent(address account) external returns (uint) {
        account; // Shh
        delegateAndReturn();
    }

    /**
     * @notice Return the borrow balance of account based on stored data
     * @param account The address whose balance should be calculated
     * @return The calculated balance
     */
    function borrowBalanceStored(address account) public view returns (uint) {
        account; // Shh
        delegateToViewAndReturn();
    }

   /**
     * @notice Accrue interest then return the up-to-date exchange rate
     * @return Calculated exchange rate scaled by 1e18
     */
    function exchangeRateCurrent() public returns (uint) {
        delegateAndReturn();
    }

    /**
     * @notice Calculates the exchange rate from the underlying to the CToken
     * @dev This function does not accrue interest before calculating the exchange rate
     * @return Calculated exchange rate scaled by 1e18
     */
    function exchangeRateStored() public view returns (uint) {
        delegateToViewAndReturn();
    }

    /**
     * @notice Get cash balance of this cToken in the underlying asset
     * @return The quantity of underlying asset owned by this contract
     */
    function getCash() external view returns (uint) {
        delegateToViewAndReturn();
    }

    /**
      * @notice Applies accrued interest to total borrows and reserves.
      * @dev This calculates interest accrued from the last checkpointed block
      *      up to the current block and writes new checkpoint to storage.
      */
    function accrueInterest() public returns (uint) {
        delegateAndReturn();
    }
    /**
     * @notice Transfers collateral tokens (this market) to the liquidator.
     * @dev Will fail unless called by another cToken during the process of liquidation.
     *   Its absolutely critical to use msg.sender as the borrowed cToken and not a parameter.
     * @param liquidator The account receiving seized collateral
     * @param borrower The account having collateral seized
     * @param seizeTokens The number of cTokens to seize
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function seize(address liquidator, address borrower, uint seizeTokens) external returns (uint) {
        liquidator; borrower; seizeTokens; // Shh
        delegateAndReturn();
    }

    /*** Admin Functions ***/

    /**
      * @notice Begins transfer of admin rights. The newPendingAdmin must call `_acceptAdmin` to finalize the
transfer.
      * @dev Admin function to begin change of admin. The newPendingAdmin must call `_acceptAdmin` to
finalize the transfer.
      * @param newPendingAdmin New pending admin.
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _setPendingAdmin(address payable newPendingAdmin) external returns (uint) {
        newPendingAdmin; // Shh
        delegateAndReturn();
    }

    /**
      * @notice Sets a new comptroller for the market
      * @dev Admin function to set a new comptroller
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _setComptroller(ComptrollerInterface newComptroller) public returns (uint) {
        newComptroller; // Shh
        delegateAndReturn();
    }

    /**
      * @notice accrues interest and sets a new reserve factor for the protocol using _setReserveFactorFresh
      * @dev Admin function to accrue interest and set a new reserve factor
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _setReserveFactor(uint newReserveFactorMantissa) external returns (uint) {
        newReserveFactorMantissa; // Shh
        delegateAndReturn();
    }

    /**
      * @notice Accepts transfer of admin rights. msg.sender must be pendingAdmin
      * @dev Admin function for pending admin to accept role and update admin
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _acceptAdmin() external returns (uint) {
        delegateAndReturn();
    }

    /**
     * @notice Accrues interest and adds reserves by transferring from admin
     * @param addAmount Amount of reserves to add
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function _addReserves(uint addAmount) external returns (uint) {
        addAmount; // Shh
        delegateAndReturn();
    }

    /**
     * @notice Accrues interest and reduces reserves by transferring to admin
     * @param reduceAmount Amount of reduction to reserves
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function _reduceReserves(uint reduceAmount) external returns (uint) {
        reduceAmount; // Shh
        delegateAndReturn();
    }

    /**
     * @notice Accrues interest and updates the interest rate model using _setInterestRateModelFresh
     * @dev Admin function to accrue interest and update the interest rate model
     * @param newInterestRateModel the new interest rate model to use
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function _setInterestRateModel(InterestRateModel newInterestRateModel) public returns (uint) {
        newInterestRateModel; // Shh
        delegateAndReturn();
    }

    /**
     * @notice Internal method to delegate execution to another contract
     * @dev It returns to the external caller whatever the implementation returns or forwards reverts
     * @param callee The contract to delegatecall
     * @param data The raw data to delegatecall
     * @return The returned bytes from the delegatecall
     */
    function delegateTo(address callee, bytes memory data) internal returns (bytes memory) {
        (bool success, bytes memory returnData) = callee.delegatecall(data);
        assembly {
            if eq(success, 0) {
                revert(add(returnData, 0x20), returndatasize)
            }
        }
        return returnData;
    }

    /**
     * @notice Delegates execution to the implementation contract
     * @dev It returns to the external caller whatever the implementation returns or forwards reverts
     * @param data The raw data to delegatecall
     * @return The returned bytes from the delegatecall
     */
    function delegateToImplementation(bytes memory data) public returns (bytes memory) {
        return delegateTo(implementation, data);
    }

    /**
     * @notice Delegates execution to an implementation contract
     * @dev It returns to the external caller whatever the implementation returns or forwards reverts
     *  There are an additional 2 prefix uints from the wrapper returndata, which we ignore since we make an
extra hop.
     * @param data The raw data to delegatecall
     * @return The returned bytes from the delegatecall
     */
    function delegateToViewImplementation(bytes memory data) public view returns (bytes memory) {
        (bool success, bytes memory returnData) =
address(this).staticcall(abi.encodeWithSignature("delegateToImplementation(bytes)", data));
        assembly {
            if eq(success, 0) {
                revert(add(returnData, 0x20), returndatasize)
            }
        }
        return abi.decode(returnData, (bytes));
    }

    function delegateToViewAndReturn() private view returns (bytes memory) {
        (bool success, ) = address(this).staticcall(abi.encodeWithSignature("delegateToImplementation(bytes)",
msg.data));

        assembly {
            let free_mem_ptr := mload(0x40)
            returndatacopy(free_mem_ptr, 0, returndatasize)

            switch success
            case 0 { revert(free_mem_ptr, returndatasize) }
            default { return(add(free_mem_ptr, 0x40), returndatasize) }
        }
    }

    function delegateAndReturn() private returns (bytes memory) {
        (bool success, ) = implementation.delegatecall(msg.data);

        assembly {
            let free_mem_ptr := mload(0x40)
            returndatacopy(free_mem_ptr, 0, returndatasize)

            switch success
            case 0 { revert(free_mem_ptr, returndatasize) }
            default { return(free_mem_ptr, returndatasize) }
        }
    }

    /**
     * @notice Delegates execution to an implementation contract
     * @dev It returns to the external caller whatever the implementation returns or forwards reverts
     */
    function () external payable {
        require(msg.value == 0,"CErc20Delegator:fallback: cannot send value to fallback");

        // delegate all other functions to current implementation
        delegateAndReturn();
    }
}
```

CHT.sol

```
pragma solidity ^0.5.16;

import "./CToken.sol";

/**
  * @title Channels's CHT Contract
  * @notice CToken which wraps HT
  * @author Channels
  */
contract CHT is CToken {
	/**
	  * @notice Construct a new CHT money market
	  * @param comptroller_ The address of the Comptroller
	  * @param interestRateModel_ The address of the interest rate model
	  * @param initialExchangeRateMantissa_ The initial exchange rate, scaled by 1e18
	  * @param name_ ERC-20 name of this token
	  * @param symbol_ ERC-20 symbol of this token
	  * @param decimals_ ERC-20 decimal precision of this token
	  * @param admin_ Address of the administrator of this token
	  */
	constructor(ComptrollerInterface comptroller_,
			InterestRateModel interestRateModel_,
			uint initialExchangeRateMantissa_,
			string memory name_,
			string memory symbol_,
			uint8 decimals_,
			address payable admin_) public {
		// Creator of the contract is admin during initialization
		admin = msg.sender;

		initialize(comptroller_, interestRateModel_, initialExchangeRateMantissa_, name_, symbol_,
decimals_);

		// Set the proper admin now that initialization is done
		admin = admin_;
	}


	/*** User Interface ***/

	/**
	  * @notice Sender supplies assets into the market and receives cTokens in exchange
	  * @dev Reverts upon any failure
	  */
	function mint() external payable {
		(uint err,) = mintInternal(msg.value);
		requireNoError(err, "mint failed");
	}

	/**
	  * @notice Sender redeems cTokens in exchange for the underlying asset
	  * @dev Accrues interest whether or not the operation succeeds, unless reverted
	  * @param redeemTokens The number of cTokens to redeem into underlying
	  * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
	  */
	function redeem(uint redeemTokens) external returns (uint) {
		return redeemInternal(redeemTokens);
	}

	/**
	  * @notice Sender redeems cTokens in exchange for a specified amount of underlying asset
	  * @dev Accrues interest whether or not the operation succeeds, unless reverted
	  * @param redeemAmount The amount of underlying to redeem
	  * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
	  */
	function redeemUnderlying(uint redeemAmount) external returns (uint) {
		return redeemUnderlyingInternal(redeemAmount);
	}

	/**
	   * @notice Sender borrows assets from the protocol to their own address
	   * @param borrowAmount The amount of the underlying asset to borrow
	   * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
	   */
	function borrow(uint borrowAmount) external returns (uint) {
		return borrowInternal(borrowAmount);
	}

	/**
	  * @notice Sender repays their own borrow
	  * @dev Reverts upon any failure
	  */
	function repayBorrow() external payable {
        (uint err,) = repayBorrowInternal(msg.value);
        requireNoError(err, "repayBorrow failed");
    }

    /**
     * @notice Sender repays a borrow belonging to borrower
     * @dev Reverts upon any failure
     * @param borrower the account with the debt being payed off
     */
    function repayBorrowBehalf(address borrower) external payable {
        (uint err,) = repayBorrowBehalfInternal(borrower, msg.value);
        requireNoError(err, "repayBorrowBehalf failed");
    }

    /**
     * @notice The sender liquidates the borrowers collateral.
     *  The collateral seized is transferred to the liquidator.
     * @dev Reverts upon any failure
     * @param borrower The borrower of this cToken to be liquidated
     * @param cTokenCollateral The market in which to seize collateral from the borrower
     */
    function liquidateBorrow(address borrower, CToken cTokenCollateral) external payable {
        (uint err,) = liquidateBorrowInternal(borrower, msg.value, cTokenCollateral);
        requireNoError(err, "liquidateBorrow failed");
    }

    /**
     * @notice Send HT to CHT to mint
     */
    function () external payable {
        (uint err,) = mintInternal(msg.value);
        requireNoError(err, "mint failed");
    }

    /*** Safe Token ***/

    /**
     * @notice Gets balance of this contract in terms of HT, before this message
     * @dev This excludes the value of the current message, if any
     * @return The quantity of HT owned by this contract
     */
    function getCashPrior() internal view returns (uint) {
        (MathError err, uint startingBalance) = subUInt(address(this).balance, msg.value);
        require(err == MathError.NO_ERROR);
        return startingBalance;
    }

    /**
     * @notice Perform the actual transfer in, which is a no-op
     * @param from Address sending the HT
     * @param amount Amount of HT being sent
     * @return The actual amount of HT transferred
     */
    function doTransferIn(address from, uint amount) internal returns (uint) {
        // Sanity checks
        require(msg.sender == from, "sender mismatch");
        require(msg.value == amount, "value mismatch");
        return amount;
    }

    function doTransferOut(address payable to, uint amount) internal {
        /* Send the HT, with minimal gas and revert on failure */
        to.transfer(amount);
    }

    function requireNoError(uint errCode, string memory message) internal pure {
        if (errCode == uint(Error.NO_ERROR)) {
            return;
        }

        bytes memory fullMessage = new bytes(bytes(message).length + 5);
        uint i;

        for (i = 0; i < bytes(message).length; i++) {
            fullMessage[i] = bytes(message)[i];
        }

        fullMessage[i+0] = byte(uint8(32));
        fullMessage[i+1] = byte(uint8(40));
        fullMessage[i+2] = byte(uint8(48 + ( errCode / 10 )));
        fullMessage[i+3] = byte(uint8(48 + ( errCode % 10 )));
        fullMessage[i+4] = byte(uint8(41));

        require(errCode == uint(Error.NO_ERROR), string(fullMessage));
    }
}
```

Comptroller.sol

```
pragma solidity ^0.5.16;

import "./CToken.sol";
import "./ErrorReporter.sol";
import "./Exponential.sol";
import "./PriceOracle.sol";
import "./ComptrollerInterface.sol";
import "./ComptrollerStorage.sol";
import "./Unitroller.sol";
import "./Can.sol";

/**
 * @title Channels's Comptroller Contract
 * @author Channels
 */
contract Comptroller is ComptrollerV3Storage, ComptrollerInterface, ComptrollerErrorReporter, Exponential {
    /// @notice Emitted when an admin supports a market
    event MarketListed(CToken cToken);

    /// @notice Emitted when an account enters a market
    event MarketEntered(CToken cToken, address account);

    /// @notice Emitted when an account exits a market
    event MarketExited(CToken cToken, address account);

    /// @notice Emitted when close factor is changed by admin
    event NewCloseFactor(uint oldCloseFactorMantissa, uint newCloseFactorMantissa);

    /// @notice Emitted when a collateral factor is changed by admin
    event NewCollateralFactor(CToken cToken, uint oldCollateralFactorMantissa, uint
newCollateralFactorMantissa);

    /// @notice Emitted when liquidation incentive is changed by admin
    event NewLiquidationIncentive(uint oldLiquidationIncentiveMantissa, uint
newLiquidationIncentiveMantissa);

    /// @notice Emitted when maxAssets is changed by admin
    event NewMaxAssets(uint oldMaxAssets, uint newMaxAssets);

    /// @notice Emitted when price oracle is changed
    event NewPriceOracle(PriceOracle oldPriceOracle, PriceOracle newPriceOracle);

    /// @notice Emitted when pause guardian is changed
    event NewPauseGuardian(address oldPauseGuardian, address newPauseGuardian);

    /// @notice Emitted when an action is paused globally
    event ActionPaused(string action, bool pauseState);

    /// @notice Emitted when an action is paused on a market
    event ActionPaused(CToken cToken, string action, bool pauseState);

    /// @notice Emitted when market caned status is changed
    event MarketCaned(CToken cToken, bool isCaned);

    /// @notice Emitted when Channels rate is changed
    event NewCanRate(uint oldCanRate, uint newCanRate);

    /// @notice Emitted when a new Channels speed is calculated for a market
    event CanSpeedUpdated(CToken indexed cToken, uint newSpeed);

    /// @notice Emitted when Channels is distributed to a supplier
    event DistributedSupplierCan(CToken indexed cToken, address indexed supplier, uint canDelta, uint
canSupplyIndex);

    /// @notice Emitted when Channels is distributed to a borrower
    event DistributedBorrowerCan(CToken indexed cToken, address indexed borrower, uint canDelta, uint
canBorrowIndex);

    /// @notice The threshold above which the flywheel transfers Channels, in wei
    uint public constant canClaimThreshold = 0.001e18;

    /// @notice The initial Channels index for a market
    uint224 public constant canInitialIndex = 1e36;

    // closeFactorMantissa must be strictly greater than this value
    uint internal constant closeFactorMinMantissa = 0.05e18; // 0.05

    // closeFactorMantissa must not exceed this value
    uint internal constant closeFactorMaxMantissa = 0.9e18; // 0.9

    // No collateralFactorMantissa may exceed this value
    uint internal constant collateralFactorMaxMantissa = 0.9e18; // 0.9

    // liquidationIncentiveMantissa must be no less than this value
```

```
uint internal constant liquidationIncentiveMinMantissa = 1.0e18; // 1.0

// liquidationIncentiveMantissa must be no greater than this value
uint internal constant liquidationIncentiveMaxMantissa = 1.5e18; // 1.5

constructor() public {
    admin = msg.sender;
}

/*** Assets You Are In ***/

/**
  * @notice Returns the assets an account has entered
  * @param account The address of the account to pull assets for
  * @return A dynamic list with the assets the account has entered
  */
function getAssetsIn(address account) external view returns (CToken[] memory) {
    CToken[] memory assetsIn = accountAssets[account];

    return assetsIn;
}

/**
  * @notice Returns whether the given account is entered in the given asset
  * @param account The address of the account to check
  * @param cToken The cToken to check
  * @return True if the account is in the asset, otherwise false.
  */
function checkMembership(address account, CToken cToken) external view returns (bool) {
    return markets[address(cToken)].accountMembership[account];
}

/**
  * @notice Add assets to be included in account liquidity calculation
  * @param cTokens The list of addresses of the cToken markets to be enabled
  * @return Success indicator for whether each corresponding market was entered
  */
function enterMarkets(address[] memory cTokens) public returns (uint[] memory) {
    uint len = cTokens.length;

    uint[] memory results = new uint[](len);
    for (uint i = 0; i < len; i++) {
        CToken cToken = CToken(cTokens[i]);

        results[i] = uint(addToMarketInternal(cToken, msg.sender));
    }

    return results;
}

/**
  * @notice Add the market to the borrower's "assets in" for liquidity calculations
  * @param cToken The market to enter
  * @param borrower The address of the account to modify
  * @return Success indicator for whether the market was entered
  */
function addToMarketInternal(CToken cToken, address borrower) internal returns (Error) {
    Market storage marketToJoin = markets[address(cToken)];

    if (!marketToJoin.isListed) {
        // market is not listed, cannot join
        return Error.MARKET_NOT_LISTED;
    }

    if (marketToJoin.accountMembership[borrower] == true) {
        // already joined
        return Error.NO_ERROR;
    }

    if (accountAssets[borrower].length >= maxAssets)    {
        // no space, cannot join
        return Error.TOO_MANY_ASSETS;
    }

    // survived the gauntlet, add to list
    // NOTE: we store these somewhat redundantly as a significant optimization
    //    this avoids having to iterate through the list for the most common use cases
    //    that is, only when we need to perform liquidity checks
    //    and not whenever we want to check if an account is in a particular market
    marketToJoin.accountMembership[borrower] = true;
    accountAssets[borrower].push(cToken);

    emit MarketEntered(cToken, borrower);

    return Error.NO_ERROR;
}
```

```
    /**
     * @notice Removes asset from sender's account liquidity calculation
     * @dev Sender must not have an outstanding borrow balance in the asset,
     *   or be providing necessary collateral for an outstanding borrow.
     * @param cTokenAddress The address of the asset to be removed
     * @return Whether or not the account successfully exited the market
     */
    function exitMarket(address cTokenAddress) external returns (uint) {
        CToken cToken = CToken(cTokenAddress);
        /* Get sender tokensHeld and amountOwed underlying from the cToken */
        (uint oErr, uint tokensHeld, uint amountOwed, ) = cToken.getAccountSnapshot(msg.sender);
        require(oErr == 0, "exitMarket: getAccountSnapshot failed"); // semi-opaque error code

        /* Fail if the sender has a borrow balance */
        if (amountOwed != 0) {
            return                                    fail(Error.NONZERO_BORROW_BALANCE,
FailureInfo.EXIT_MARKET_BALANCE_OWED);
        }

        /* Fail if the sender is not permitted to redeem all of their tokens */
        uint allowed = redeemAllowedInternal(cTokenAddress, msg.sender, tokensHeld);
        if (allowed != 0) {
            return failOpaque(Error.REJECTION, FailureInfo.EXIT_MARKET_REJECTION, allowed);
        }

        Market storage marketToExit = markets[address(cToken)];

        /* Return true if the sender is not already   'in '   the market */
        if (!marketToExit.accountMembership[msg.sender]) {
            return uint(Error.NO_ERROR);
        }

        /* Set cToken account membership to false */
        delete marketToExit.accountMembership[msg.sender];

        /* Delete cToken from the account ' s list of assets */
        // load into memory for faster iteration
        CToken[] memory userAssetList = accountAssets[msg.sender];
        uint len = userAssetList.length;
        uint assetIndex = len;
        for (uint i = 0; i < len; i++) {
            if (userAssetList[i] == cToken) {
                assetIndex = i;
                break;
            }
        }

        // We *must* have found the asset in the list or our redundant data structure is broken
        assert(assetIndex < len);

        // copy last item in list to location of item to be removed, reduce length by 1
        CToken[] storage storedList = accountAssets[msg.sender];
        storedList[assetIndex] = storedList[storedList.length - 1];
        storedList.length--;

        emit MarketExited(cToken, msg.sender);

        return uint(Error.NO_ERROR);
    }

    /*** Policy Hooks ***/

    /**
     * @notice Checks if the account should be allowed to mint tokens in the given market
     * @param cToken The market to verify the mint against
     * @param minter The account which would get the minted tokens
     * @param mintAmount The amount of underlying being supplied to the market in exchange for tokens
     * @return 0 if the mint is allowed, otherwise a semi-opaque error code (See ErrorReporter.sol)
     */
    function mintAllowed(address cToken, address minter, uint mintAmount) external returns (uint) {
        // Pausing is a very serious situation - we revert to sound the alarms
        require(!mintGuardianPaused[cToken], "mint is paused");

        // Shh - currently unused
        minter;
        mintAmount;

        if (!markets[cToken].isListed) {
            return uint(Error.MARKET_NOT_LISTED);
        }

        // Keep the flywheel moving
        updateCanSupplyIndex(cToken);
        distributeSupplierCan(cToken, minter, false);

        return uint(Error.NO_ERROR);
    }
    /**
     * @notice Validates mint and reverts on rejection. May emit logs.
     * @param cToken Asset being minted
     * @param minter The address minting the tokens
     * @param actualMintAmount The amount of the underlying asset being minted
     * @param mintTokens The number of tokens being minted
     */
    function mintVerify(address cToken, address minter, uint actualMintAmount, uint mintTokens) external {
        // Shh - currently unused
        cToken;
        minter;
        actualMintAmount;
        mintTokens;

        // Shh - we don't ever want this hook to be marked pure
        if (false) {
            maxAssets = maxAssets;
        }
    }

    /**
     * @notice Checks if the account should be allowed to redeem tokens in the given market
     * @param cToken The market to verify the redeem against
     * @param redeemer The account which would redeem the tokens
     * @param redeemTokens The number of cTokens to exchange for the underlying asset in the market
     * @return 0 if the redeem is allowed, otherwise a semi-opaque error code (See ErrorReporter.sol)
     */
    function redeemAllowed(address cToken, address redeemer, uint redeemTokens) external returns (uint) {
        uint allowed = redeemAllowedInternal(cToken, redeemer, redeemTokens);
        if (allowed != uint(Error.NO_ERROR)) {
            return allowed;
        }

        // Keep the flywheel moving
        updateCanSupplyIndex(cToken);
        distributeSupplierCan(cToken, redeemer, false);

        return uint(Error.NO_ERROR);
    }

    function redeemAllowedInternal(address cToken, address redeemer, uint redeemTokens) internal view
returns (uint) {
        if (!markets[cToken].isListed) {
            return uint(Error.MARKET_NOT_LISTED);
        }

        /* If the redeemer is not 'in' the market, then we can bypass the liquidity check */
        if (!markets[cToken].accountMembership[redeemer]) {
            return uint(Error.NO_ERROR);
        }

        /* Otherwise, perform a hypothetical liquidity check to guard against shortfall */
        (Error err, , uint shortfall) = getHypotheticalAccountLiquidityInternal(redeemer, CToken(cToken),
redeemTokens, 0);
        if (err != Error.NO_ERROR) {
            return uint(err);
        }
        if (shortfall > 0) {
            return uint(Error.INSUFFICIENT_LIQUIDITY);
        }

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Validates redeem and reverts on rejection. May emit logs.
     * @param cToken Asset being redeemed
     * @param redeemer The address redeeming the tokens
     * @param redeemAmount The amount of the underlying asset being redeemed
     * @param redeemTokens The number of tokens being redeemed
     */
    function redeemVerify(address cToken, address redeemer, uint redeemAmount, uint redeemTokens) external {
        // Shh - currently unused
        cToken;
        redeemer;

        // Require tokens is zero or amount is also zero
        if (redeemTokens == 0 && redeemAmount > 0) {
            revert("redeemTokens zero");
        }
    }

    /**
     * @notice Checks if the account should be allowed to borrow the underlying asset of the given market
     * @param cToken The market to verify the borrow against
     * @param borrower The account which would borrow the asset
     * @param borrowAmount The amount of underlying the account would borrow
     * @return 0 if the borrow is allowed, otherwise a semi-opaque error code (See ErrorReporter.sol)
     */
    function borrowAllowed(address cToken, address borrower, uint borrowAmount) external returns (uint) {
        // Pausing is a very serious situation - we revert to sound the alarms
        require(!borrowGuardianPaused[cToken], "borrow is paused");

        if (!markets[cToken].isListed) {
            return uint(Error.MARKET_NOT_LISTED);
        }

        if (!markets[cToken].accountMembership[borrower]) {
            // only cTokens may call borrowAllowed if borrower not in market
            require(msg.sender == cToken, "sender must be cToken");

            // attempt to add borrower to the market
            Error err = addToMarketInternal(CToken(msg.sender), borrower);
            if (err != Error.NO_ERROR) {
                return uint(err);
            }

            // it should be impossible to break the important invariant
            assert(markets[cToken].accountMembership[borrower]);
        }

        if (oracle.getUnderlyingPrice(CToken(cToken)) == 0) {
            return uint(Error.PRICE_ERROR);
        }

        (Error err, , uint shortfall) = getHypotheticalAccountLiquidityInternal(borrower, CToken(cToken), 0,
borrowAmount);
        if (err != Error.NO_ERROR) {
            return uint(err);
        }
        if (shortfall > 0) {
            return uint(Error.INSUFFICIENT_LIQUIDITY);
        }

        // Keep the flywheel moving
        Exp memory borrowIndex = Exp({mantissa: CToken(cToken).borrowIndex()});
        updateCanBorrowIndex(cToken, borrowIndex);
        distributeBorrowerCan(cToken, borrower, borrowIndex, false);

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Validates borrow and reverts on rejection. May emit logs.
     * @param cToken Asset whose underlying is being borrowed
     * @param borrower The address borrowing the underlying
     * @param borrowAmount The amount of the underlying asset requested to borrow
     */
    function borrowVerify(address cToken, address borrower, uint borrowAmount) external {
        // Shh - currently unused
        cToken;
        borrower;
        borrowAmount;

        // Shh - we don't ever want this hook to be marked pure
        if (false) {
            maxAssets = maxAssets;
        }
    }

    /**
     * @notice Checks if the account should be allowed to repay a borrow in the given market
     * @param cToken The market to verify the repay against
     * @param payer The account which would repay the asset
     * @param borrower The account which would borrowed the asset
     * @param repayAmount The amount of the underlying asset the account would repay
     * @return 0 if the repay is allowed, otherwise a semi-opaque error code (See ErrorReporter.sol)
     */
    function repayBorrowAllowed(
        address cToken,
        address payer,
        address borrower,
        uint repayAmount) external returns (uint) {
        // Shh - currently unused
        payer;
        borrower;
        repayAmount;

        if (!markets[cToken].isListed) {
            return uint(Error.MARKET_NOT_LISTED);
        }

        // Keep the flywheel moving
        Exp memory borrowIndex = Exp({mantissa: CToken(cToken).borrowIndex()});
        updateCanBorrowIndex(cToken, borrowIndex);
        distributeBorrowerCan(cToken, borrower, borrowIndex, false);

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Validates repayBorrow and reverts on rejection. May emit logs.
     * @param cToken Asset being repaid
     * @param payer The address repaying the borrow
     * @param borrower The address of the borrower
     * @param actualRepayAmount The amount of underlying being repaid
     */
    function repayBorrowVerify(
        address cToken,
        address payer,
        address borrower,
        uint actualRepayAmount,
        uint borrowerIndex) external {
        // Shh - currently unused
        cToken;
        payer;
        borrower;
        actualRepayAmount;
        borrowerIndex;

        // Shh - we don't ever want this hook to be marked pure
        if (false) {
            maxAssets = maxAssets;
        }
    }

    /**
     * @notice Checks if the liquidation should be allowed to occur
     * @param cTokenBorrowed Asset which was borrowed by the borrower
     * @param cTokenCollateral Asset which was used as collateral and will be seized
     * @param liquidator The address repaying the borrow and seizing the collateral
     * @param borrower The address of the borrower
     * @param repayAmount The amount of underlying being repaid
     */
    function liquidateBorrowAllowed(
        address cTokenBorrowed,
        address cTokenCollateral,
        address liquidator,
        address borrower,
        uint repayAmount) external returns (uint) {
        // Shh - currently unused
        liquidator;

        if (!markets[cTokenBorrowed].isListed || !markets[cTokenCollateral].isListed) {
            return uint(Error.MARKET_NOT_LISTED);
        }

        /* The borrower must have shortfall in order to be liquidatable */
        (Error err, , uint shortfall) = getAccountLiquidityInternal(borrower);
        if (err != Error.NO_ERROR) {
            return uint(err);
        }
        if (shortfall == 0) {
            return uint(Error.INSUFFICIENT_SHORTFALL);
        }

        /* The liquidator may not repay more than what is allowed by the closeFactor */
        uint borrowBalance = CToken(cTokenBorrowed).borrowBalanceStored(borrower);
        (MathError mathErr, uint maxClose) = mulScalarTruncate(Exp({mantissa: closeFactorMantissa}),
borrowBalance);
        if (mathErr != MathError.NO_ERROR) {
            return uint(Error.MATH_ERROR);
        }
        if (repayAmount > maxClose) {
            return uint(Error.TOO_MUCH_REPAY);
        }

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Validates liquidateBorrow and reverts on rejection. May emit logs.
     * @param cTokenBorrowed Asset which was borrowed by the borrower
     * @param cTokenCollateral Asset which was used as collateral and will be seized
     * @param liquidator The address repaying the borrow and seizing the collateral
     * @param borrower The address of the borrower
     * @param actualRepayAmount The amount of underlying being repaid
     */
    function liquidateBorrowVerify(
        address cTokenBorrowed,
        address cTokenCollateral,
        address liquidator,
        address borrower,
        uint actualRepayAmount,
        uint seizeTokens) external {
        // Shh - currently unused
        cTokenBorrowed;
        cTokenCollateral;
        liquidator;
        borrower;
        actualRepayAmount;
        seizeTokens;

        // Shh - we don't ever want this hook to be marked pure
        if (false) {
            maxAssets = maxAssets;
        }
    }

    /**
     * @notice Checks if the seizing of assets should be allowed to occur
     * @param cTokenCollateral Asset which was used as collateral and will be seized
     * @param cTokenBorrowed Asset which was borrowed by the borrower
     * @param liquidator The address repaying the borrow and seizing the collateral
     * @param borrower The address of the borrower
     * @param seizeTokens The number of collateral tokens to seize
     */
    function seizeAllowed(
        address cTokenCollateral,
        address cTokenBorrowed,
        address liquidator,
        address borrower,
        uint seizeTokens) external returns (uint) {
        // Pausing is a very serious situation - we revert to sound the alarms
        require(!seizeGuardianPaused, "seize is paused");

        // Shh - currently unused
        seizeTokens;

        if (!markets[cTokenCollateral].isListed || !markets[cTokenBorrowed].isListed) {
            return uint(Error.MARKET_NOT_LISTED);
        }

        if (CToken(cTokenCollateral).comptroller() != CToken(cTokenBorrowed).comptroller()) {
            return uint(Error.ChannelsTROLLER_MISMATCH);
        }

        // Keep the flywheel moving
        updateCanSupplyIndex(cTokenCollateral);
        distributeSupplierCan(cTokenCollateral, borrower, false);
        distributeSupplierCan(cTokenCollateral, liquidator, false);

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Validates seize and reverts on rejection. May emit logs.
     * @param cTokenCollateral Asset which was used as collateral and will be seized
     * @param cTokenBorrowed Asset which was borrowed by the borrower
     * @param liquidator The address repaying the borrow and seizing the collateral
     * @param borrower The address of the borrower
     * @param seizeTokens The number of collateral tokens to seize
     */
    function seizeVerify(
        address cTokenCollateral,
        address cTokenBorrowed,
        address liquidator,
        address borrower,
        uint seizeTokens) external {
        // Shh - currently unused
        cTokenCollateral;
        cTokenBorrowed;
        liquidator;
        borrower;
        seizeTokens;

        // Shh - we don't ever want this hook to be marked pure
        if (false) {
            maxAssets = maxAssets;
        }
    }

    /**
     * @notice Checks if the account should be allowed to transfer tokens in the given market
     * @param cToken The market to verify the transfer against
     * @param src The account which sources the tokens
     * @param dst The account which receives the tokens
     * @param transferTokens The number of cTokens to transfer
     * @return 0 if the transfer is allowed, otherwise a semi-opaque error code (See ErrorReporter.sol)
     */
    function transferAllowed(address cToken, address src, address dst, uint transferTokens) external returns (uint)
{
        // Pausing is a very serious situation - we revert to sound the alarms
        require(!transferGuardianPaused, "transfer is paused");

        // Currently the only consideration is whether or not
        //    the src is allowed to redeem this many tokens
        uint allowed = redeemAllowedInternal(cToken, src, transferTokens);
        if (allowed != uint(Error.NO_ERROR)) {
            return allowed;
        }

        // Keep the flywheel moving
        updateCanSupplyIndex(cToken);
        distributeSupplierCan(cToken, src, false);
        distributeSupplierCan(cToken, dst, false);

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Validates transfer and reverts on rejection. May emit logs.
     * @param cToken Asset being transferred
     * @param src The account which sources the tokens
     * @param dst The account which receives the tokens
     * @param transferTokens The number of cTokens to transfer
     */
    function transferVerify(address cToken, address src, address dst, uint transferTokens) external {
        // Shh - currently unused
        cToken;
        src;
        dst;
        transferTokens;

        // Shh - we don't ever want this hook to be marked pure
        if (false) {
            maxAssets = maxAssets;
        }
    }

    /*** Liquidity/Liquidation Calculations ***/

    /**
     * @dev Local vars for avoiding stack-depth limits in calculating account liquidity.
     *  Note that `cTokenBalance` is the number of cTokens the account owns in the market,
     *  whereas `borrowBalance` is the amount of underlying that the account has borrowed.
     */
    struct AccountLiquidityLocalVars {
        uint sumCollateral;
        uint sumBorrowPlusEffects;
        uint cTokenBalance;
        uint borrowBalance;
        uint exchangeRateMantissa;
        uint oraclePriceMantissa;
        Exp collateralFactor;
        Exp exchangeRate;
        Exp oraclePrice;
        Exp tokensToDenom;
    }

    /**
     * @notice Determine the current account liquidity wrt collateral requirements
     * @return (possible error code (semi-opaque),
                account liquidity in excess of collateral requirements,
     *          account shortfall below collateral requirements)
     */
    function getAccountLiquidity(address account) public view returns (uint, uint, uint) {
        (Error err, uint liquidity, uint shortfall) = getHypotheticalAccountLiquidityInternal(account, CToken(0),
0, 0);

        return (uint(err), liquidity, shortfall);
    }

    /**
     * @notice Determine the current account liquidity wrt collateral requirements
     * @return (possible error code,
                account liquidity in excess of collateral requirements,
     *          account shortfall below collateral requirements)
     */
    function getAccountLiquidityInternal(address account) internal view returns (Error, uint, uint) {
        return getHypotheticalAccountLiquidityInternal(account, CToken(0), 0, 0);
    }

    /**
```

```
     * @notice Determine what the account liquidity would be if the given amounts were redeemed/borrowed
     * @param cTokenModify The market to hypothetically redeem/borrow in
     * @param account The account to determine liquidity for
     * @param redeemTokens The number of tokens to hypothetically redeem
     * @param borrowAmount The amount of underlying to hypothetically borrow
     * @return (possible error code (semi-opaque),
                hypothetical account liquidity in excess of collateral requirements,
     *          hypothetical account shortfall below collateral requirements)
     */
    function getHypotheticalAccountLiquidity(
        address account,
        address cTokenModify,
        uint redeemTokens,
        uint borrowAmount) public view returns (uint, uint, uint) {
        (Error err, uint liquidity, uint shortfall) = getHypotheticalAccountLiquidityInternal(account,
CToken(cTokenModify), redeemTokens, borrowAmount);
        return (uint(err), liquidity, shortfall);
    }

    /**
     * @notice Determine what the account liquidity would be if the given amounts were redeemed/borrowed
     * @param cTokenModify The market to hypothetically redeem/borrow in
     * @param account The account to determine liquidity for
     * @param redeemTokens The number of tokens to hypothetically redeem
     * @param borrowAmount The amount of underlying to hypothetically borrow
     * @dev Note that we calculate the exchangeRateStored for each collateral cToken using stored data,
     *  without calculating accumulated interest.
     * @return (possible error code,
                hypothetical account liquidity in excess of collateral requirements,
     *          hypothetical account shortfall below collateral requirements)
     */
    function getHypotheticalAccountLiquidityInternal(
        address account,
        CToken cTokenModify,
        uint redeemTokens,
        uint borrowAmount) internal view returns (Error, uint, uint) {

        AccountLiquidityLocalVars memory vars; // Holds all our calculation results
        uint oErr;
        MathError mErr;

        // For each asset the account is in
        CToken[] memory assets = accountAssets[account];
        for (uint i = 0; i < assets.length; i++) {
            CToken asset = assets[i];

            // Read the balances and exchange rate from the cToken
            (oErr, vars.cTokenBalance, vars.borrowBalance, vars.exchangeRateMantissa) =
asset.getAccountSnapshot(account);
            if (oErr != 0) { // semi-opaque error code, we assume NO_ERROR == 0 is invariant between
upgrades
                return (Error.SNAPSHOT_ERROR, 0, 0);
            }
            vars.collateralFactor = Exp({mantissa: markets[address(asset)].collateralFactorMantissa});
            vars.exchangeRate = Exp({mantissa: vars.exchangeRateMantissa});

            // Get the normalized price of the asset
            vars.oraclePriceMantissa = oracle.getUnderlyingPrice(asset);
            if (vars.oraclePriceMantissa == 0) {
                return (Error.PRICE_ERROR, 0, 0);
            }
            vars.oraclePrice = Exp({mantissa: vars.oraclePriceMantissa});

            // Pre-canute a conversion factor from tokens -> ht (normalized price value)
            (mErr, vars.tokensToDenom) = mulExp3(vars.collateralFactor, vars.exchangeRate,
vars.oraclePrice);
            if (mErr != MathError.NO_ERROR) {
                return (Error.MATH_ERROR, 0, 0);
            }

            // sumCollateral += tokensToDenom * cTokenBalance
            (mErr, vars.sumCollateral) = mulScalarTruncateAddUInt(vars.tokensToDenom,
vars.cTokenBalance, vars.sumCollateral);
            if (mErr != MathError.NO_ERROR) {
                return (Error.MATH_ERROR, 0, 0);
            }

            // sumBorrowPlusEffects += oraclePrice * borrowBalance
            (mErr, vars.sumBorrowPlusEffects) = mulScalarTruncateAddUInt(vars.oraclePrice,
vars.borrowBalance, vars.sumBorrowPlusEffects);
            if (mErr != MathError.NO_ERROR) {
                return (Error.MATH_ERROR, 0, 0);
            }

            // Calculate effects of interacting with cTokenModify
            if (asset == cTokenModify) {
                // redeem effect
```

```
                    // sumBorrowPlusEffects += tokensToDenom * redeemTokens
                    (mErr, vars.sumBorrowPlusEffects) = mulScalarTruncateAddUInt(vars.tokensToDenom,
redeemTokens, vars.sumBorrowPlusEffects);
                    if (mErr != MathError.NO_ERROR) {
                        return (Error.MATH_ERROR, 0, 0);
                    }

                    // borrow effect
                    // sumBorrowPlusEffects += oraclePrice * borrowAmount
                    (mErr, vars.sumBorrowPlusEffects) = mulScalarTruncateAddUInt(vars.oraclePrice,
borrowAmount, vars.sumBorrowPlusEffects);
                    if (mErr != MathError.NO_ERROR) {
                        return (Error.MATH_ERROR, 0, 0);
                    }
                }
            }

            // These are safe, as the underflow condition is checked first
            if (vars.sumCollateral > vars.sumBorrowPlusEffects) {
                return (Error.NO_ERROR, vars.sumCollateral - vars.sumBorrowPlusEffects, 0);
            } else {
                return (Error.NO_ERROR, 0, vars.sumBorrowPlusEffects - vars.sumCollateral);
            }
        }

        /**
         * @notice Calculate number of tokens of collateral asset to seize given an underlying amount
         * @dev Used in liquidation (called in cToken.liquidateBorrowFresh)
         * @param cTokenBorrowed The address of the borrowed cToken
         * @param cTokenCollateral The address of the collateral cToken
         * @param actualRepayAmount The amount of cTokenBorrowed underlying to convert into
cTokenCollateral tokens
         * @return (errorCode, number of cTokenCollateral tokens to be seized in a liquidation)
         */
        function liquidateCalculateSeizeTokens(address cTokenBorrowed, address cTokenCollateral, uint
actualRepayAmount) external view returns (uint, uint) {
            /* Read oracle prices for borrowed and collateral markets */
            uint priceBorrowedMantissa = oracle.getUnderlyingPrice(CToken(cTokenBorrowed));
            uint priceCollateralMantissa = oracle.getUnderlyingPrice(CToken(cTokenCollateral));
            if (priceBorrowedMantissa == 0 || priceCollateralMantissa == 0) {
                return (uint(Error.PRICE_ERROR), 0);
            }

            /*
             * Get the exchange rate and calculate the number of collateral tokens to seize:
             *   seizeAmount = actualRepayAmount * liquidationIncentive * priceBorrowed / priceCollateral
             *   seizeTokens = seizeAmount / exchangeRate
             *       = actualRepayAmount * (liquidationIncentive * priceBorrowed) / (priceCollateral *
exchangeRate)
             */
            uint exchangeRateMantissa = CToken(cTokenCollateral).exchangeRateStored(); // Note: reverts on
error
            uint seizeTokens;
            Exp memory numerator;
            Exp memory denominator;
            Exp memory ratio;
            MathError mathErr;

            (mathErr, numerator) = mulExp(liquidationIncentiveMantissa, priceBorrowedMantissa);
            if (mathErr != MathError.NO_ERROR) {
                return (uint(Error.MATH_ERROR), 0);
            }

            (mathErr, denominator) = mulExp(priceCollateralMantissa, exchangeRateMantissa);
            if (mathErr != MathError.NO_ERROR) {
                return (uint(Error.MATH_ERROR), 0);
            }

            (mathErr, ratio) = divExp(numerator, denominator);
            if (mathErr != MathError.NO_ERROR) {
                return (uint(Error.MATH_ERROR), 0);
            }

            (mathErr, seizeTokens) = mulScalarTruncate(ratio, actualRepayAmount);
            if (mathErr != MathError.NO_ERROR) {
                return (uint(Error.MATH_ERROR), 0);
            }

            return (uint(Error.NO_ERROR), seizeTokens);
        }

        /*** Admin Functions ***/

        /**
          * @notice Sets a new price oracle for the comptroller
          * @dev Admin function to set a new price oracle
          * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
```

```
     */
    function _setPriceOracle(PriceOracle newOracle) public returns (uint) {
        // Check caller is admin
        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.SET_PRICE_ORACLE_OWNER_CHECK);
        }

        // Track the old oracle for the comptroller
        PriceOracle oldOracle = oracle;

        // Set comptroller's oracle to newOracle
        oracle = newOracle;

        // Emit NewPriceOracle(oldOracle, newOracle)
        emit NewPriceOracle(oldOracle, newOracle);

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Sets the closeFactor used when liquidating borrows
     * @dev Admin function to set closeFactor
     * @param newCloseFactorMantissa New close factor, scaled by 1e18
     * @return uint 0=success, otherwise a failure. (See ErrorReporter for details)
     */
    function _setCloseFactor(uint newCloseFactorMantissa) external returns (uint) {
        // Check caller is admin
        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.SET_CLOSE_FACTOR_OWNER_CHECK);
        }

        Exp memory newCloseFactorExp = Exp({mantissa: newCloseFactorMantissa});
        Exp memory lowLimit = Exp({mantissa: closeFactorMinMantissa});
        if (lessThanOrEqualExp(newCloseFactorExp, lowLimit)) {
            return                                         fail(Error.INVALID_CLOSE_FACTOR,
FailureInfo.SET_CLOSE_FACTOR_VALIDATION);
        }

        Exp memory highLimit = Exp({mantissa: closeFactorMaxMantissa});
        if (lessThanExp(highLimit, newCloseFactorExp)) {
            return                                         fail(Error.INVALID_CLOSE_FACTOR,
FailureInfo.SET_CLOSE_FACTOR_VALIDATION);
        }

        uint oldCloseFactorMantissa = closeFactorMantissa;
        closeFactorMantissa = newCloseFactorMantissa;
        emit NewCloseFactor(oldCloseFactorMantissa, closeFactorMantissa);

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Sets the collateralFactor for a market
     * @dev Admin function to set per-market collateralFactor
     * @param cToken The market to set the factor on
     * @param newCollateralFactorMantissa The new collateral factor, scaled by 1e18
     * @return uint 0=success, otherwise a failure. (See ErrorReporter for details)
     */
    function _setCollateralFactor(CToken cToken, uint newCollateralFactorMantissa) external returns (uint) {
        // Check caller is admin
        if (msg.sender != admin) {
            return                                                 fail(Error.UNAUTHORIZED,
FailureInfo.SET_COLLATERAL_FACTOR_OWNER_CHECK);
        }

        // Verify market is listed
        Market storage market = markets[address(cToken)];
        if (!market.isListed) {
            return                                             fail(Error.MARKET_NOT_LISTED,
FailureInfo.SET_COLLATERAL_FACTOR_NO_EXISTS);
        }

        Exp memory newCollateralFactorExp = Exp({mantissa: newCollateralFactorMantissa});

        // Check collateral factor <= 0.9
        Exp memory highLimit = Exp({mantissa: collateralFactorMaxMantissa});
        if (lessThanExp(highLimit, newCollateralFactorExp)) {
            return                                   fail(Error.INVALID_COLLATERAL_FACTOR,
FailureInfo.SET_COLLATERAL_FACTOR_VALIDATION);
        }

        // If collateral factor != 0, fail if price == 0
        if (newCollateralFactorMantissa != 0 && oracle.getUnderlyingPrice(cToken) == 0) {
            return                                                   fail(Error.PRICE_ERROR,
FailureInfo.SET_COLLATERAL_FACTOR_WITHOUT_PRICE);
        }
        // Set market's collateral factor to new collateral factor, remember old value
        uint oldCollateralFactorMantissa = market.collateralFactorMantissa;
        market.collateralFactorMantissa = newCollateralFactorMantissa;

        // Emit event with asset, old collateral factor, and new collateral factor
        emit NewCollateralFactor(cToken, oldCollateralFactorMantissa, newCollateralFactorMantissa);

        return uint(Error.NO_ERROR);
    }

    /**
      * @notice Sets maxAssets which controls how many markets can be entered
      * @dev Admin function to set maxAssets
      * @param newMaxAssets New max assets
      * @return uint 0=success, otherwise a failure. (See ErrorReporter for details)
      */
    function _setMaxAssets(uint newMaxAssets) external returns (uint) {
        // Check caller is admin
        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.SET_MAX_ASSETS_OWNER_CHECK);
        }

        uint oldMaxAssets = maxAssets;
        maxAssets = newMaxAssets;
        emit NewMaxAssets(oldMaxAssets, newMaxAssets);

        return uint(Error.NO_ERROR);
    }

    /**
      * @notice Sets liquidationIncentive
      * @dev Admin function to set liquidationIncentive
      * @param newLiquidationIncentiveMantissa New liquidationIncentive scaled by 1e18
      * @return uint 0=success, otherwise a failure. (See ErrorReporter for details)
      */
    function _setLiquidationIncentive(uint newLiquidationIncentiveMantissa) external returns (uint) {
        // Check caller is admin
        if (msg.sender != admin) {
            return                                                          fail(Error.UNAUTHORIZED,
FailureInfo.SET_LIQUIDATION_INCENTIVE_OWNER_CHECK);
        }

        // Check de-scaled min <= newLiquidationIncentive <= max
        Exp memory newLiquidationIncentive = Exp({mantissa: newLiquidationIncentiveMantissa});
        Exp memory minLiquidationIncentive = Exp({mantissa: liquidationIncentiveMinMantissa});
        if (lessThanExp(newLiquidationIncentive, minLiquidationIncentive)) {
            return                                    fail(Error.INVALID_LIQUIDATION_INCENTIVE,
FailureInfo.SET_LIQUIDATION_INCENTIVE_VALIDATION);
        }

        Exp memory maxLiquidationIncentive = Exp({mantissa: liquidationIncentiveMaxMantissa});
        if (lessThanExp(maxLiquidationIncentive, newLiquidationIncentive)) {
            return                                    fail(Error.INVALID_LIQUIDATION_INCENTIVE,
FailureInfo.SET_LIQUIDATION_INCENTIVE_VALIDATION);
        }

        // Save current value for use in log
        uint oldLiquidationIncentiveMantissa = liquidationIncentiveMantissa;

        // Set liquidation incentive to new incentive
        liquidationIncentiveMantissa = newLiquidationIncentiveMantissa;

        // Emit event with old incentive, new incentive
        emit NewLiquidationIncentive(oldLiquidationIncentiveMantissa, newLiquidationIncentiveMantissa);

        return uint(Error.NO_ERROR);
    }

    /**
      * @notice Add the market to the markets mapping and set it as listed
      * @dev Admin function to set isListed and add support for the market
      * @param cToken The address of the market (token) to list
      * @return uint 0=success, otherwise a failure. (See enum Error for details)
      */
    function _supportMarket(CToken cToken) external returns (uint) {
        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.SUPPORT_MARKET_OWNER_CHECK);
        }

        if (markets[address(cToken)].isListed) {
            return fail(Error.MARKET_ALREADY_LISTED, FailureInfo.SUPPORT_MARKET_EXISTS);
        }

        cToken.isCToken(); // Sanity check to make sure its really a CToken

        markets[address(cToken)] = Market({isListed: true, isCaned: false, collateralFactorMantissa: 0});
        _addMarketInternal(address(cToken));

        emit MarketListed(cToken);

        return uint(Error.NO_ERROR);
    }

    function _addMarketInternal(address cToken) internal {
        for (uint i = 0; i < allMarkets.length; i ++) {
            require(allMarkets[i] != CToken(cToken), "market already added");
        }
        allMarkets.push(CToken(cToken));
    }

    /**
      * @notice Admin function to change the Pause Guardian
      * @param newPauseGuardian The address of the new Pause Guardian
      * @return uint 0=success, otherwise a failure. (See enum Error for details)
      */
    function _setPauseGuardian(address newPauseGuardian) public returns (uint) {
        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.SET_PAUSE_GUARDIAN_OWNER_CHECK);
        }

        // Save current value for inclusion in log
        address oldPauseGuardian = pauseGuardian;

        // Store pauseGuardian with value newPauseGuardian
        pauseGuardian = newPauseGuardian;

        // Emit NewPauseGuardian(OldPauseGuardian, NewPauseGuardian)
        emit NewPauseGuardian(oldPauseGuardian, pauseGuardian);

        return uint(Error.NO_ERROR);
    }

    function _setMintPaused(CToken cToken, bool state) public returns (bool) {
        require(markets[address(cToken)].isListed, "cannot pause a market that is not listed");
        require(msg.sender == pauseGuardian || msg.sender == admin, "only pause guardian and admin can
pause");
        require(msg.sender == admin || state == true, "only admin can unpause");

        mintGuardianPaused[address(cToken)] = state;
        emit ActionPaused(cToken, "Mint", state);
        return state;
    }

    function _setBorrowPaused(CToken cToken, bool state) public returns (bool) {
        require(markets[address(cToken)].isListed, "cannot pause a market that is not listed");
        require(msg.sender == pauseGuardian || msg.sender == admin, "only pause guardian and admin can
pause");
        require(msg.sender == admin || state == true, "only admin can unpause");

        borrowGuardianPaused[address(cToken)] = state;
        emit ActionPaused(cToken, "Borrow", state);
        return state;
    }

    function _setTransferPaused(bool state) public returns (bool) {
        require(msg.sender == pauseGuardian || msg.sender == admin, "only pause guardian and admin can
pause");
        require(msg.sender == admin || state == true, "only admin can unpause");

        transferGuardianPaused = state;
        emit ActionPaused("Transfer", state);
        return state;
    }

    function _setSeizePaused(bool state) public returns (bool) {
        require(msg.sender == pauseGuardian || msg.sender == admin, "only pause guardian and admin can
pause");
        require(msg.sender == admin || state == true, "only admin can unpause");

        seizeGuardianPaused = state;
        emit ActionPaused("Seize", state);
        return state;
    }

    function _become(Unitroller unitroller) public {
        require(msg.sender == unitroller.admin(), "only unitroller admin can change brains");
        require(unitroller._acceptImplementation() == 0, "change not authorized");
    }

    /**
      * @notice Checks caller is admin, or this contract is becoming the new implementation
      */
    function adminOrInitializing() internal view returns (bool) {
        return msg.sender == admin || msg.sender == comptrollerImplementation;
    }

    /*** Can Distribution ***/

    /**
     * @notice Recalculate and update Channels speeds for all Channels markets
     */
    function refreshCanSpeeds() public {
        require(msg.sender == tx.origin, "only externally owned accounts may refresh speeds");
        refreshCanSpeedsInternal();
    }

    function refreshCanSpeedsInternal() internal {
        CToken[] memory allMarkets_ = allMarkets;

        for (uint i = 0; i < allMarkets_.length; i++) {
            CToken cToken = allMarkets_[i];
            Exp memory borrowIndex = Exp({mantissa: cToken.borrowIndex()});
            updateCanSupplyIndex(address(cToken));
            updateCanBorrowIndex(address(cToken), borrowIndex);
        }

        Exp memory totalUtility = Exp({mantissa: 0});
        Exp[] memory utilities = new Exp[](allMarkets_.length);
        for (uint i = 0; i < allMarkets_.length; i++) {
            CToken cToken = allMarkets_[i];
            if (markets[address(cToken)].isCaned) {
                Exp memory assetPrice = Exp({mantissa: oracle.getUnderlyingPrice(cToken)});
                Exp memory utility = mul_(assetPrice, cToken.totalBorrows());
                utilities[i] = utility;
                totalUtility = add_(totalUtility, utility);
            }
        }

        for (uint i = 0; i < allMarkets_.length; i++) {
            CToken cToken = allMarkets[i];
            uint newSpeed = totalUtility.mantissa > 0 ? mul_(canRate, div_(utilities[i], totalUtility)) : 0;
            canSpeeds[address(cToken)] = newSpeed;
            emit CanSpeedUpdated(cToken, newSpeed);
        }
    }

    /**
     * @notice Accrue Channels to the market by updating the supply index
     * @param cToken The market whose supply index to update
     */
    function updateCanSupplyIndex(address cToken) internal {
        CanMarketState storage supplyState = canSupplyState[cToken];
        uint supplySpeed = canSpeeds[cToken];
        uint blockNumber = getBlockNumber();
        uint deltaBlocks = sub_(blockNumber, uint(supplyState.block));
        if (deltaBlocks > 0 && supplySpeed > 0) {
            uint supplyTokens = CToken(cToken).totalSupply();
            uint canAccrued = mul_(deltaBlocks, supplySpeed);
            Double memory ratio = supplyTokens > 0 ? fraction(canAccrued, supplyTokens) :
Double({mantissa: 0});
            Double memory index = add_(Double({mantissa: supplyState.index}), ratio);
            canSupplyState[cToken] = CanMarketState({
                index: safe224(index.mantissa, "new index exceeds 224 bits"),
                block: safe32(blockNumber, "block number exceeds 32 bits")
            });
        } else if (deltaBlocks > 0) {
            supplyState.block = safe32(blockNumber, "block number exceeds 32 bits");
        }
    }

    /**
     * @notice Accrue Channels to the market by updating the borrow index
     * @param cToken The market whose borrow index to update
     */
    function updateCanBorrowIndex(address cToken, Exp memory marketBorrowIndex) internal {
        CanMarketState storage borrowState = canBorrowState[cToken];
        uint borrowSpeed = canSpeeds[cToken];
        uint blockNumber = getBlockNumber();
        uint deltaBlocks = sub_(blockNumber, uint(borrowState.block));
        if (deltaBlocks > 0 && borrowSpeed > 0) {
            uint borrowAmount = div_(CToken(cToken).totalBorrows(), marketBorrowIndex);
            uint canAccrued = mul_(deltaBlocks, borrowSpeed);
            Double memory ratio = borrowAmount > 0 ? fraction(canAccrued, borrowAmount) :
Double({mantissa: 0});
            Double memory index = add_(Double({mantissa: borrowState.index}), ratio);
            canBorrowState[cToken] = CanMarketState({
                index: safe224(index.mantissa, "new index exceeds 224 bits"),
                block: safe32(blockNumber, "block number exceeds 32 bits")
            });
        } else if (deltaBlocks > 0) {
                borrowState.block = safe32(blockNumber, "block number exceeds 32 bits");
            }
        }

        /**
          * @notice Calculate Channels accrued by a supplier and possibly transfer it to them
          * @param cToken The market in which the supplier is interacting
          * @param supplier The address of the supplier to distribute Channels to
          */
        function distributeSupplierCan(address cToken, address supplier, bool distributeAll) internal {
            CanMarketState storage supplyState = canSupplyState[cToken];
            Double memory supplyIndex = Double({mantissa: supplyState.index});
            Double memory supplierIndex = Double({mantissa: canSupplierIndex[cToken][supplier]});
            canSupplierIndex[cToken][supplier] = supplyIndex.mantissa;

            if (supplierIndex.mantissa == 0 && supplyIndex.mantissa > 0) {
                supplierIndex.mantissa = canInitialIndex;
            }

            Double memory deltaIndex = sub_(supplyIndex, supplierIndex);
            uint supplierTokens = CToken(cToken).balanceOf(supplier);
            uint supplierDelta = mul_(supplierTokens, deltaIndex);
            uint supplierAccrued = add_(canAccrued[supplier], supplierDelta);
            canAccrued[supplier] = transferCan(supplier, supplierAccrued, distributeAll ? 0 : canClaimThreshold);
            emit DistributedSupplierCan(CToken(cToken), supplier, supplierDelta, supplyIndex.mantissa);
        }

        /**
          * @notice Calculate Channels accrued by a borrower and possibly transfer it to them
          * @dev Borrowers will not begin to accrue until after the first interaction with the protocol.
          * @param cToken The market in which the borrower is interacting
          * @param borrower The address of the borrower to distribute Channels to
          */
        function distributeBorrowerCan(address cToken, address borrower, Exp memory marketBorrowIndex, bool
distributeAll) internal {
            CanMarketState storage borrowState = canBorrowState[cToken];
            Double memory borrowIndex = Double({mantissa: borrowState.index});
            Double memory borrowerIndex = Double({mantissa: canBorrowerIndex[cToken][borrower]});
            canBorrowerIndex[cToken][borrower] = borrowIndex.mantissa;

            if (borrowerIndex.mantissa > 0) {
                Double memory deltaIndex = sub_(borrowIndex, borrowerIndex);
                uint          borrowerAmount          =          div_(CToken(cToken).borrowBalanceStored(borrower),
marketBorrowIndex);
                uint borrowerDelta = mul_(borrowerAmount, deltaIndex);
                uint borrowerAccrued = add_(canAccrued[borrower], borrowerDelta);
                canAccrued[borrower]   =   transferCan(borrower,   borrowerAccrued,   distributeAll   ?   0   :
canClaimThreshold);
                emit DistributedBorrowerCan(CToken(cToken), borrower, borrowerDelta, borrowIndex.mantissa);
            }
        }

        /**
          * @notice Transfer Channels to the user, if they are above the threshold
          * @dev Note: If there is not enough Channels, we do not perform the transfer all.
          * @param user The address of the user to transfer Channels to
          * @param userAccrued The amount of Channels to (possibly) transfer
          * @return The amount of Channels which was NOT transferred to the user
          */
        function transferCan(address user, uint userAccrued, uint threshold) internal returns (uint) {
            if (userAccrued >= threshold && userAccrued > 0) {
                Can can = Can(getCanAddress());
                uint canRemaining = can.balanceOf(address(this));
                if (userAccrued <= canRemaining) {
                    can.transfer(user, userAccrued);
                    return 0;
                }
            }
            return userAccrued;
        }

        /**
          * @notice Claim all the can accrued by holder in all markets
          * @param holder The address to claim Channels for
          */
        function claimCan(address holder) public {
            return claimCan(holder, allMarkets);
        }

        /**
          * @notice Claim all the can accrued by holder in the specified markets
          * @param holder The address to claim Channels for
          * @param cTokens The list of markets to claim Channels in
          */
        function claimCan(address holder, CToken[] memory cTokens) public {
            address[] memory holders = new address[](1);
            holders[0] = holder;
        claimCan(holders, cTokens, true, true);
    }

    /**
     * @notice Claim all can accrued by the holders
     * @param holders The addresses to claim Channels for
     * @param cTokens The list of markets to claim Channels in
     * @param borrowers Whether or not to claim Channels earned by borrowing
     * @param suppliers Whether or not to claim Channels earned by supplying
     */
    function claimCan(address[] memory holders, CToken[] memory cTokens, bool borrowers, bool suppliers)
public {
        for (uint i = 0; i < cTokens.length; i++) {
            CToken cToken = cTokens[i];
            require(markets[address(cToken)].isListed, "market must be listed");
            if (borrowers == true) {
                Exp memory borrowIndex = Exp({mantissa: cToken.borrowIndex()});
                updateCanBorrowIndex(address(cToken), borrowIndex);
                for (uint j = 0; j < holders.length; j++) {
                    distributeBorrowerCan(address(cToken), holders[j], borrowIndex, true);
                }
            }
            if (suppliers == true) {
                updateCanSupplyIndex(address(cToken));
                for (uint j = 0; j < holders.length; j++) {
                    distributeSupplierCan(address(cToken), holders[j], true);
                }
            }
        }
    }

    /*** Can Distribution Admin ***/

    /**
     * @notice Set the amount of Channels distributed per block
     * @param canRate_ The amount of Channels wei per block to distribute
     */
    function _setCanRate(uint canRate_) public {
        require(adminOrInitializing(), "only admin can change can rate");

        uint oldRate = canRate;
        canRate = canRate_;
        emit NewCanRate(oldRate, canRate_);

        refreshCanSpeedsInternal();
    }

    /**
     * @notice Add markets to canMarkets, allowing them to earn Channels in the flywheel
     * @param cTokens The addresses of the markets to add
     */
    function _addCanMarkets(address[] memory cTokens) public {
        require(adminOrInitializing(), "only admin can add can market");

        for (uint i = 0; i < cTokens.length; i++) {
            _addCanMarketInternal(cTokens[i]);
        }

        refreshCanSpeedsInternal();
    }

    function _addCanMarketInternal(address cToken) internal {
        Market storage market = markets[cToken];
        require(market.isListed == true, "can market is not listed");
        require(market.isCaned == false, "can market already added");

        market.isCaned = true;
        emit MarketCaned(CToken(cToken), true);

        if (canSupplyState[cToken].index == 0 && canSupplyState[cToken].block == 0) {
            canSupplyState[cToken] = CanMarketState({
                index: canInitialIndex,
                block: safe32(getBlockNumber(), "block number exceeds 32 bits")
            });
        }

        if (canBorrowState[cToken].index == 0 && canBorrowState[cToken].block == 0) {
            canBorrowState[cToken] = CanMarketState({
                index: canInitialIndex,
                block: safe32(getBlockNumber(), "block number exceeds 32 bits")
            });
        }
    }

    /**
     * @notice Remove a market from canMarkets, preventing it from earning Channels in the flywheel
     * @param cToken The address of the market to drop
     */
    function _dropCanMarket(address cToken) public {
        require(msg.sender == admin, "only admin can drop can market");

        Market storage market = markets[cToken];
        require(market.isCaned == true, "market is not a can market");

        market.isCaned = false;
        emit MarketCaned(CToken(cToken), false);

        refreshCanSpeedsInternal();
    }

    /**
     * @notice Return all of the markets
     * @dev The automatic getter may be used to access an individual market.
     * @return The list of market addresses
     */
    function getAllMarkets() public view returns (CToken[] memory) {
        return allMarkets;
    }

    function getBlockNumber() public view returns (uint) {
        return block.number;
    }

    /**
     * @notice Return the address of the Channels token
     * @return The address of Channels
     */
    function getCanAddress() public view returns (address) {
        return 0x0d14deE0D75D9B2b8cAe378979E5bFca06266cb4;
    }
}
```

ComptrollerInterface.sol

```
pragma solidity ^0.5.16;

contract ComptrollerInterface {
    /// @notice Indicator that this is a Comptroller contract (for inspection)
    bool public constant isComptroller = true;

    /*** Assets You Are In ***/

    function enterMarkets(address[] calldata cTokens) external returns (uint[] memory);
    function exitMarket(address cToken) external returns (uint);

    /*** Policy Hooks ***/

    function mintAllowed(address cToken, address minter, uint mintAmount) external returns (uint);
    function mintVerify(address cToken, address minter, uint mintAmount, uint mintTokens) external;

    function redeemAllowed(address cToken, address redeemer, uint redeemTokens) external returns (uint);
    function redeemVerify(address cToken, address redeemer, uint redeemAmount, uint redeemTokens) external;

    function borrowAllowed(address cToken, address borrower, uint borrowAmount) external returns (uint);
    function borrowVerify(address cToken, address borrower, uint borrowAmount) external;

    function repayBorrowAllowed(
        address cToken,
        address payer,
        address borrower,
        uint repayAmount) external returns (uint);
    function repayBorrowVerify(
        address cToken,
        address payer,
        address borrower,
        uint repayAmount,
        uint borrowerIndex) external;

    function liquidateBorrowAllowed(
        address cTokenBorrowed,
        address cTokenCollateral,
        address liquidator,
        address borrower,
        uint repayAmount) external returns (uint);
    function liquidateBorrowVerify(
        address cTokenBorrowed,
        address cTokenCollateral,
        address liquidator,
        address borrower,
        uint repayAmount,
        uint seizeTokens) external;

    function seizeAllowed(
        address cTokenCollateral,
        address cTokenBorrowed,
        address liquidator,
        address borrower,
        uint seizeTokens) external returns (uint);
    function seizeVerify(
        address cTokenCollateral,
        address cTokenBorrowed,
        address liquidator,
        address borrower,
        uint seizeTokens) external;

    function transferAllowed(address cToken, address src, address dst, uint transferTokens) external returns
(uint);
    function transferVerify(address cToken, address src, address dst, uint transferTokens) external;

    /*** Liquidity/Liquidation Calculations ***/

    function liquidateCalculateSeizeTokens(
        address cTokenBorrowed,
        address cTokenCollateral,
        uint repayAmount) external view returns (uint, uint);
}
```

ComptrollerStorage.sol

```
pragma solidity ^0.5.16;

import "./CToken.sol";
import "./PriceOracle.sol";

contract UnitrollerAdminStorage {
    /**
    * @notice Administrator for this contract
    */
    address public admin;

    /**
    * @notice Pending administrator for this contract
    */
    address public pendingAdmin;

    /**
    * @notice Active brains of Unitroller
    */
    address public comptrollerImplementation;

    /**
    * @notice Pending brains of Unitroller
    */
    address public pendingComptrollerImplementation;
}

contract ComptrollerV1Storage is UnitrollerAdminStorage {

    /**
     * @notice Oracle which gives the price of any given asset
     */
    PriceOracle public oracle;

    /**
     * @notice Multiplier used to calculate the maximum repayAmount when liquidating a borrow
     */
    uint public closeFactorMantissa;

    /**
     * @notice Multiplier representing the discount on collateral that a liquidator receives
     */
    uint public liquidationIncentiveMantissa;

    /**
     * @notice Max number of assets a single account can participate in (borrow or use as collateral)
     */
    uint public maxAssets;

    /**
     * @notice Per-account mapping of "assets you are in", capped by maxAssets
     */
    mapping(address => CToken[]) public accountAssets;

}

contract ComptrollerV2Storage is ComptrollerV1Storage {
    struct Market {
        /// @notice Whether or not this market is listed
        bool isListed;
        /**
         * @notice Multiplier representing the most one can borrow against their collateral in this market.
         *   For instance, 0.9 to allow borrowing 90% of collateral value.
         *   Must be between 0 and 1, and stored as a mantissa.
         */
        uint collateralFactorMantissa;

        /// @notice Per-market mapping of "accounts in this asset"
        mapping(address => bool) accountMembership;

        /// @notice Whether or not this market receives Channels
        bool isCaned;
    }

    /**
     * @notice Official mapping of cTokens -> Market metadata
     * @dev Used e.g. to determine if a market is supported
     */
    mapping(address => Market) public markets;


    /**
     * @notice The Pause Guardian can pause certain actions as a safety mechanism.
     *   Actions which allow users to remove their own assets cannot be paused.
     *   Liquidation / seizing / transfer can only be paused globally, not by market.
     */
    address public pauseGuardian;
    bool public _mintGuardianPaused;
    bool public _borrowGuardianPaused;
    bool public transferGuardianPaused;
    bool public seizeGuardianPaused;
    mapping(address => bool) public mintGuardianPaused;
    mapping(address => bool) public borrowGuardianPaused;
}

contract ComptrollerV3Storage is ComptrollerV2Storage {
    struct CanMarketState {
        /// @notice The market's last updated canBorrowIndex or canSupplyIndex
        uint224 index;

        /// @notice The block number the index was last updated at
        uint32 block;
    }

    /// @notice A list of all markets
    CToken[] public allMarkets;

    /// @notice The rate at which the flywheel distributes Channels, per block
    uint public canRate;

    /// @notice The portion of canRate that each market currently receives
    mapping(address => uint) public canSpeeds;

    /// @notice The Channels market supply state for each market
    mapping(address => CanMarketState) public canSupplyState;

    /// @notice The Channels market borrow state for each market
    mapping(address => CanMarketState) public canBorrowState;

    /// @notice The Channels borrow index for each market for each supplier as of the last time they accrued
Channels
    mapping(address => mapping(address => uint)) public canSupplierIndex;

    /// @notice The Channels borrow index for each market for each borrower as of the last time they accrued
Channels
    mapping(address => mapping(address => uint)) public canBorrowerIndex;

    /// @notice The Channels accrued but not yet transferred to each user
    mapping(address => uint) public canAccrued;
}
```

CToken.sol

```
pragma solidity ^0.5.16;

import "./ComptrollerInterface.sol";
import "./CTokenInterfaces.sol";
import "./ErrorReporter.sol";
import "./Exponential.sol";
import "./EIP20Interface.sol";
import "./EIP20NonStandardInterface.sol";
import "./InterestRateModel.sol";

/**
 * @title Channels's CToken Contract
 * @notice Abstract base for CTokens
```

```
  * @author Channels
  */
contract CToken is CTokenInterface, Exponential, TokenErrorReporter {
    /**
      * @notice Initialize the money market
      * @param comptroller_ The address of the Comptroller
      * @param interestRateModel_ The address of the interest rate model
      * @param initialExchangeRateMantissa_ The initial exchange rate, scaled by 1e18
      * @param name_ EIP-20 name of this token
      * @param symbol_ EIP-20 symbol of this token
      * @param decimals_ EIP-20 decimal precision of this token
      */
    function initialize(ComptrollerInterface comptroller_,
                        InterestRateModel interestRateModel_,
                        uint initialExchangeRateMantissa_,
                        string memory name_,
                        string memory symbol_,
                        uint8 decimals_) public {
        require(msg.sender == admin, "only admin may initialize the market");
        require(accrualBlockNumber == 0 && borrowIndex == 0, "market may only be initialized once");

        // Set initial exchange rate
        initialExchangeRateMantissa = initialExchangeRateMantissa_;
        require(initialExchangeRateMantissa > 0, "initial exchange rate must be greater than zero.");

        // Set the comptroller
        uint err = _setComptroller(comptroller_);
        require(err == uint(Error.NO_ERROR), "setting comptroller failed");

        // Initialize block number and borrow index (block number mocks depend on comptroller being set)
        accrualBlockNumber = getBlockNumber();
        borrowIndex = mantissaOne;

        // Set the interest rate model (depends on block number / borrow index)
        err = _setInterestRateModelFresh(interestRateModel_);
        require(err == uint(Error.NO_ERROR), "setting interest rate model failed");

        name = name_;
        symbol = symbol_;
        decimals = decimals_;

        // The counter starts true to prevent changing it from zero to non-zero (i.e. smaller cost/refund)
        _notEntered = true;
    }

    /**
      * @notice Transfer `tokens` tokens from `src` to `dst` by `spender`
      * @dev Called by both `transfer` and `transferFrom` internally
      * @param spender The address of the account performing the transfer
      * @param src The address of the source account
      * @param dst The address of the destination account
      * @param tokens The number of tokens to transfer
      * @return Whether or not the transfer succeeded
      */
    function transferTokens(address spender, address src, address dst, uint tokens) internal returns (uint) {
        /* Fail if transfer not allowed */
        uint allowed = comptroller.transferAllowed(address(this), src, dst, tokens);
        if (allowed != 0) {
            return                              failOpaque(Error.ChannelsTROLLER_REJECTION,
FailureInfo.TRANSFER_ChannelsTROLLER_REJECTION, allowed);
        }

        /* Do not allow self-transfers */
        if (src == dst) {
            return fail(Error.BAD_INPUT, FailureInfo.TRANSFER_NOT_ALLOWED);
        }

        /* Get the allowance, infinite for the account owner */
        uint startingAllowance = 0;
        if (spender == src) {
            startingAllowance = uint(-1);
        } else {
            startingAllowance = transferAllowances[src][spender];
        }

        /* Do the calculations, checking for {under,over}flow */
        MathError mathErr;
        uint allowanceNew;
        uint srcTokensNew;
        uint dstTokensNew;

        (mathErr, allowanceNew) = subUInt(startingAllowance, tokens);
        if (mathErr != MathError.NO_ERROR) {
            return fail(Error.MATH_ERROR, FailureInfo.TRANSFER_NOT_ALLOWED);
        }

        (mathErr, srcTokensNew) = subUInt(accountTokens[src], tokens);
        if (mathErr != MathError.NO_ERROR) {
            return fail(Error.MATH_ERROR, FailureInfo.TRANSFER_NOT_ENOUGH);
        }

        (mathErr, dstTokensNew) = addUInt(accountTokens[dst], tokens);
        if (mathErr != MathError.NO_ERROR) {
            return fail(Error.MATH_ERROR, FailureInfo.TRANSFER_TOO_MUCH);
        }

        /////////////////////////
        // EFFECTS & INTERACTIONS
        // (No safe failures beyond this point)

        accountTokens[src] = srcTokensNew;
        accountTokens[dst] = dstTokensNew;

        /* Eat some of the allowance (if necessary) */
        if (startingAllowance != uint(-1)) {
            transferAllowances[src][spender] = allowanceNew;
        }

        /* We emit a Transfer event */
        emit Transfer(src, dst, tokens);

        comptroller.transferVerify(address(this), src, dst, tokens);

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Transfer `amount` tokens from `msg.sender` to `dst`
     * @param dst The address of the destination account
     * @param amount The number of tokens to transfer
     * @return Whether or not the transfer succeeded
     */
    function transfer(address dst, uint256 amount) external nonReentrant returns (bool) {
        return transferTokens(msg.sender, msg.sender, dst, amount) == uint(Error.NO_ERROR);
    }

    /**
     * @notice Transfer `amount` tokens from `src` to `dst`
     * @param src The address of the source account
     * @param dst The address of the destination account
     * @param amount The number of tokens to transfer
     * @return Whether or not the transfer succeeded
     */
    function transferFrom(address src, address dst, uint256 amount) external nonReentrant returns (bool) {
        return transferTokens(msg.sender, src, dst, amount) == uint(Error.NO_ERROR);
    }

    /**
     * @notice Approve `spender` to transfer up to `amount` from `src`
     * @dev This will overwrite the approval amount for `spender`
     *  and is subject to issues noted [here](https://eips.ethereum.org/EIPS/eip-20#approve)
     * @param spender The address of the account which may transfer tokens
     * @param amount The number of tokens that are approved (-1 means infinite)
     * @return Whether or not the approval succeeded
     */
    function approve(address spender, uint256 amount) external returns (bool) {
        address src = msg.sender;
        transferAllowances[src][spender] = amount;
        emit Approval(src, spender, amount);
        return true;
    }

    /**
     * @notice Get the current allowance from `owner` for `spender`
     * @param owner The address of the account which owns the tokens to be spent
     * @param spender The address of the account which may transfer tokens
     * @return The number of tokens allowed to be spent (-1 means infinite)
     */
    function allowance(address owner, address spender) external view returns (uint256) {
        return transferAllowances[owner][spender];
    }

    /**
     * @notice Get the token balance of the `owner`
     * @param owner The address of the account to query
     * @return The number of tokens owned by `owner`
     */
    function balanceOf(address owner) external view returns (uint256) {
        return accountTokens[owner];
    }

    /**
     * @notice Get the underlying balance of the `owner`
     * @dev This also accrues interest in a transaction
     * @param owner The address of the account to query
     * @return The amount of underlying owned by `owner`
     */
    function balanceOfUnderlying(address owner) external returns (uint) {
        Exp memory exchangeRate = Exp({mantissa: exchangeRateCurrent()});
        (MathError mErr, uint balance) = mulScalarTruncate(exchangeRate, accountTokens[owner]);
        require(mErr == MathError.NO_ERROR, "balance could not be calculated");
        return balance;
    }

    /**
     * @notice Get a snapshot of the account's balances, and the cached exchange rate
     * @dev This is used by comptroller to more efficiently perform liquidity checks.
     * @param account Address of the account to snapshot
     * @return (possible error, token balance, borrow balance, exchange rate mantissa)
     */
    function getAccountSnapshot(address account) external view returns (uint, uint, uint, uint) {
        uint cTokenBalance = accountTokens[account];
        uint borrowBalance;
        uint exchangeRateMantissa;

        MathError mErr;

        (mErr, borrowBalance) = borrowBalanceStoredInternal(account);
        if (mErr != MathError.NO_ERROR) {
            return (uint(Error.MATH_ERROR), 0, 0, 0);
        }

        (mErr, exchangeRateMantissa) = exchangeRateStoredInternal();
        if (mErr != MathError.NO_ERROR) {
            return (uint(Error.MATH_ERROR), 0, 0, 0);
        }

        return (uint(Error.NO_ERROR), cTokenBalance, borrowBalance, exchangeRateMantissa);
    }

    /**
     * @dev Function to simply retrieve block number
     *  This exists mainly for inheriting test contracts to stub this result.
     */
    function getBlockNumber() internal view returns (uint) {
        return block.number;
    }

    /**
     * @notice Returns the current per-block borrow interest rate for this cToken
     * @return The borrow interest rate per block, scaled by 1e18
     */
    function borrowRatePerBlock() external view returns (uint) {
        return interestRateModel.getBorrowRate(getCashPrior(), totalBorrows, totalReserves);
    }

    /**
     * @notice Returns the current per-block supply interest rate for this cToken
     * @return The supply interest rate per block, scaled by 1e18
     */
    function supplyRatePerBlock() external view returns (uint) {
        return      interestRateModel.getSupplyRate(getCashPrior(),      totalBorrows,      totalReserves,
reserveFactorMantissa);
    }

    /**
     * @notice Returns the current total borrows plus accrued interest
     * @return The total borrows with interest
     */
    function totalBorrowsCurrent() external nonReentrant returns (uint) {
        require(accrueInterest() == uint(Error.NO_ERROR), "accrue interest failed");
        return totalBorrows;
    }

    /**
     * @notice Accrue interest to updated borrowIndex and then calculate account's borrow balance using the
updated borrowIndex
     * @param account The address whose balance should be calculated after updating borrowIndex
     * @return The calculated balance
     */
    function borrowBalanceCurrent(address account) external nonReentrant returns (uint) {
        require(accrueInterest() == uint(Error.NO_ERROR), "accrue interest failed");
        return borrowBalanceStored(account);
    }

    /**
     * @notice Return the borrow balance of account based on stored data
     * @param account The address whose balance should be calculated
     * @return The calculated balance
     */
    function borrowBalanceStored(address account) public view returns (uint) {
        (MathError err, uint result) = borrowBalanceStoredInternal(account);
        require(err == MathError.NO_ERROR, "borrowBalanceStored: borrowBalanceStoredInternal failed");
        return result;
    }

    /**
     * @notice Return the borrow balance of account based on stored data
     * @param account The address whose balance should be calculated
     * @return (error code, the calculated balance or 0 if error code is non-zero)
     */
    function borrowBalanceStoredInternal(address account) internal view returns (MathError, uint) {
        /* Note: we do not assert that the market is up to date */
        MathError mathErr;
        uint principalTimesIndex;
        uint result;

        /* Get borrowBalance and borrowIndex */
        BorrowSnapshot storage borrowSnapshot = accountBorrows[account];

        /* If borrowBalance = 0 then borrowIndex is likely also 0.
         * Rather than failing the calculation with a division by 0, we immediately return 0 in this case.
         */
        if (borrowSnapshot.principal == 0) {
            return (MathError.NO_ERROR, 0);
        }

        /* Calculate new borrow balance using the interest index:
         *   recentBorrowBalance = borrower.borrowBalance * market.borrowIndex / borrower.borrowIndex
         */
        (mathErr, principalTimesIndex) = mulUInt(borrowSnapshot.principal, borrowIndex);
        if (mathErr != MathError.NO_ERROR) {
            return (mathErr, 0);
        }

        (mathErr, result) = divUInt(principalTimesIndex, borrowSnapshot.interestIndex);
        if (mathErr != MathError.NO_ERROR) {
            return (mathErr, 0);
        }

        return (MathError.NO_ERROR, result);
    }

    /**
     * @notice Accrue interest then return the up-to-date exchange rate
     * @return Calculated exchange rate scaled by 1e18
     */
    function exchangeRateCurrent() public nonReentrant returns (uint) {
        require(accrueInterest() == uint(Error.NO_ERROR), "accrue interest failed");
        return exchangeRateStored();
    }

    /**
     * @notice Calculates the exchange rate from the underlying to the CToken
     * @dev This function does not accrue interest before calculating the exchange rate
     * @return Calculated exchange rate scaled by 1e18
     */
    function exchangeRateStored() public view returns (uint) {
        (MathError err, uint result) = exchangeRateStoredInternal();
        require(err == MathError.NO_ERROR, "exchangeRateStored: exchangeRateStoredInternal failed");
        return result;
    }

    /**
     * @notice Calculates the exchange rate from the underlying to the CToken
     * @dev This function does not accrue interest before calculating the exchange rate
     * @return (error code, calculated exchange rate scaled by 1e18)
     */
    function exchangeRateStoredInternal() internal view returns (MathError, uint) {
        uint _totalSupply = totalSupply;
        if (_totalSupply == 0) {
            /*
             * If there are no tokens minted:
             *   exchangeRate = initialExchangeRate
             */
            return (MathError.NO_ERROR, initialExchangeRateMantissa);
        } else {
            /*
             * Otherwise:
             *   exchangeRate = (totalCash + totalBorrows - totalReserves) / totalSupply
             */
            uint totalCash = getCashPrior();
            uint cashPlusBorrowsMinusReserves;
            Exp memory exchangeRate;
            MathError mathErr;

            (mathErr,    cashPlusBorrowsMinusReserves)    =    addThenSubUInt(totalCash,    totalBorrows,
totalReserves);
```

```
                if (mathErr != MathError.NO_ERROR) {
                    return (mathErr, 0);
                }

                (mathErr, exchangeRate) = getExp(cashPlusBorrowsMinusReserves, _totalSupply);
                if (mathErr != MathError.NO_ERROR) {
                    return (mathErr, 0);
                }

                return (MathError.NO_ERROR, exchangeRate.mantissa);
            }
        }

        /**
         * @notice Get cash balance of this cToken in the underlying asset
         * @return The quantity of underlying asset owned by this contract
         */
        function getCash() external view returns (uint) {
            return getCashPrior();
        }

        /**
         * @notice Applies accrued interest to total borrows and reserves
         * @dev This calculates interest accrued from the last checkpointed block
         *      up to the current block and writes new checkpoint to storage.
         */
        function accrueInterest() public returns (uint) {
            /* Remember the initial block number */
            uint currentBlockNumber = getBlockNumber();
            uint accrualBlockNumberPrior = accrualBlockNumber;

            /* Short-circuit accumulating 0 interest */
            if (accrualBlockNumberPrior == currentBlockNumber) {
                return uint(Error.NO_ERROR);
            }

            /* Read the previous values out of storage */
            uint cashPrior = getCashPrior();
            uint borrowsPrior = totalBorrows;
            uint reservesPrior = totalReserves;
            uint borrowIndexPrior = borrowIndex;

            /* Calculate the current borrow interest rate */
            uint      borrowRateMantissa      =      interestRateModel.getBorrowRate(cashPrior,      borrowsPrior,
reservesPrior);
            require(borrowRateMantissa <= borrowRateMaxMantissa, "borrow rate is absurdly high");

            /* Calculate the number of blocks elapsed since the last accrual */
            (MathError mathErr, uint blockDelta) = subUInt(currentBlockNumber, accrualBlockNumberPrior);
            require(mathErr == MathError.NO_ERROR, "could not calculate block delta");

            /*
             * Calculate the interest accumulated into borrows and reserves and the new index:
             *   simpleInterestFactor = borrowRate * blockDelta
             *   interestAccumulated = simpleInterestFactor * totalBorrows
             *   totalBorrowsNew = interestAccumulated + totalBorrows
             *   totalReservesNew = interestAccumulated * reserveFactor + totalReserves
             *   borrowIndexNew = simpleInterestFactor * borrowIndex + borrowIndex
             */

            Exp memory simpleInterestFactor;
            uint interestAccumulated;
            uint totalBorrowsNew;
            uint totalReservesNew;
            uint borrowIndexNew;

            (mathErr, simpleInterestFactor) = mulScalar(Exp({mantissa: borrowRateMantissa}), blockDelta);
            if (mathErr != MathError.NO_ERROR) {
                return                                                    failOpaque(Error.MATH_ERROR,
FailureInfo.ACCRUE_INTEREST_SIMPLE_INTEREST_FACTOR_CALCULATION_FAILED, uint(mathErr));
            }

            (mathErr, interestAccumulated) = mulScalarTruncate(simpleInterestFactor, borrowsPrior);
            if (mathErr != MathError.NO_ERROR) {
                return                                                    failOpaque(Error.MATH_ERROR,
FailureInfo.ACCRUE_INTEREST_ACCUMULATED_INTEREST_CALCULATION_FAILED, uint(mathErr));
            }

            (mathErr, totalBorrowsNew) = addUInt(interestAccumulated, borrowsPrior);
            if (mathErr != MathError.NO_ERROR) {
                return                                                    failOpaque(Error.MATH_ERROR,
FailureInfo.ACCRUE_INTEREST_NEW_TOTAL_BORROWS_CALCULATION_FAILED, uint(mathErr));
            }

            (mathErr,  totalReservesNew)  =  mulScalarTruncateAddUInt(Exp({mantissa:  reserveFactorMantissa}),
interestAccumulated, reservesPrior);
            if (mathErr != MathError.NO_ERROR) {
```

```
            return                                                   failOpaque(Error.MATH_ERROR,
FailureInfo.ACCRUE_INTEREST_NEW_TOTAL_RESERVES_CALCULATION_FAILED, uint(mathErr));
        }

        (mathErr, borrowIndexNew) = mulScalarTruncateAddUInt(simpleInterestFactor, borrowIndexPrior,
borrowIndexPrior);
        if (mathErr != MathError.NO_ERROR) {
            return                                                   failOpaque(Error.MATH_ERROR,
FailureInfo.ACCRUE_INTEREST_NEW_BORROW_INDEX_CALCULATION_FAILED, uint(mathErr));
        }

        /////////////////////////
        // EFFECTS & INTERACTIONS
        // (No safe failures beyond this point)

        /* We write the previously calculated values into storage */
        accrualBlockNumber = currentBlockNumber;
        borrowIndex = borrowIndexNew;
        totalBorrows = totalBorrowsNew;
        totalReserves = totalReservesNew;

        /* We emit an AccrueInterest event */
        emit AccrueInterest(cashPrior, interestAccumulated, borrowIndexNew, totalBorrowsNew);

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Sender supplies assets into the market and receives cTokens in exchange
     * @dev Accrues interest whether or not the operation succeeds, unless reverted
     * @param mintAmount The amount of the underlying asset to supply
     * @return (uint, uint) An error code (0=success, otherwise a failure, see ErrorReporter.sol), and the actual
mint amount.
     */
    function mintInternal(uint mintAmount) internal nonReentrant returns (uint, uint) {
        uint error = accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but we still want to log the fact that an attempted borrow
failed
            return (fail(Error(error), FailureInfo.MINT_ACCRUE_INTEREST_FAILED), 0);
        }
        // mintFresh emits the actual Mint event if successful and logs on errors, so we don't need to
        return mintFresh(msg.sender, mintAmount);
    }

    struct MintLocalVars {
        Error err;
        MathError mathErr;
        uint exchangeRateMantissa;
        uint mintTokens;
        uint totalSupplyNew;
        uint accountTokensNew;
        uint actualMintAmount;
    }

    /**
     * @notice User supplies assets into the market and receives cTokens in exchange
     * @dev Assumes interest has already been accrued up to the current block
     * @param minter The address of the account which is supplying the assets
     * @param mintAmount The amount of the underlying asset to supply
     * @return (uint, uint) An error code (0=success, otherwise a failure, see ErrorReporter.sol), and the actual
mint amount.
     */
    function mintFresh(address minter, uint mintAmount) internal returns (uint, uint) {
        /* Fail if mint not allowed */
        uint allowed = comptroller.mintAllowed(address(this), minter, mintAmount);
        if (allowed != 0) {
            return                                   (failOpaque(Error.ChannelsTROLLER_REJECTION,
FailureInfo.MINT_ChannelsTROLLER_REJECTION, allowed), 0);
        }

        /* Verify market's block number equals current block number */
        if (accrualBlockNumber != getBlockNumber()) {
            return (fail(Error.MARKET_NOT_FRESH, FailureInfo.MINT_FRESHNESS_CHECK), 0);
        }

        MintLocalVars memory vars;

        (vars.mathErr, vars.exchangeRateMantissa) = exchangeRateStoredInternal();
        if (vars.mathErr != MathError.NO_ERROR) {
            return                                                  (failOpaque(Error.MATH_ERROR,
FailureInfo.MINT_EXCHANGE_RATE_READ_FAILED, uint(vars.mathErr)), 0);
        }

        /////////////////////////
        // EFFECTS & INTERACTIONS
        // (No safe failures beyond this point)
        /*
         *  We call `doTransferIn` for the minter and the mintAmount.
         *  Note: The cToken must handle variations between ERC-20 and ETH underlying.
         *  `doTransferIn` reverts if anything goes wrong, since we can't be sure if
         *  side-effects occurred. The function returns the amount actually transferred,
         *  in case of a fee. On success, the cToken holds an additional `actualMintAmount`
         *  of cash.
         */
        vars.actualMintAmount = doTransferIn(minter, mintAmount);

        /*
         * We get the current exchange rate and calculate the number of cTokens to be minted:
         *  mintTokens = actualMintAmount / exchangeRate
         */

        (vars.mathErr, vars.mintTokens) = divScalarByExpTruncate(vars.actualMintAmount, Exp({mantissa:
vars.exchangeRateMantissa}));
        require(vars.mathErr == MathError.NO_ERROR, "MINT_EXCHANGE_CALCULATION_FAILED");

        /*
         * We calculate the new total supply of cTokens and minter token balance, checking for overflow:
         *  totalSupplyNew = totalSupply + mintTokens
         *  accountTokensNew = accountTokens[minter] + mintTokens
         */
        (vars.mathErr, vars.totalSupplyNew) = addUInt(totalSupply, vars.mintTokens);
        require(vars.mathErr                        ==                        MathError.NO_ERROR,
"MINT_NEW_TOTAL_SUPPLY_CALCULATION_FAILED");

        (vars.mathErr, vars.accountTokensNew) = addUInt(accountTokens[minter], vars.mintTokens);
        require(vars.mathErr                        ==                        MathError.NO_ERROR,
"MINT_NEW_ACCOUNT_BALANCE_CALCULATION_FAILED");

        /* We write previously calculated values into storage */
        totalSupply = vars.totalSupplyNew;
        accountTokens[minter] = vars.accountTokensNew;

        /* We emit a Mint event, and a Transfer event */
        emit Mint(minter, vars.actualMintAmount, vars.mintTokens);
        emit Transfer(address(this), minter, vars.mintTokens);

        /* We call the defense hook */
        comptroller.mintVerify(address(this), minter, vars.actualMintAmount, vars.mintTokens);

        return (uint(Error.NO_ERROR), vars.actualMintAmount);
    }

    /**
     * @notice Sender redeems cTokens in exchange for the underlying asset
     * @dev Accrues interest whether or not the operation succeeds, unless reverted
     * @param redeemTokens The number of cTokens to redeem into underlying
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function redeemInternal(uint redeemTokens) internal nonReentrant returns (uint) {
        uint error = accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but we still want to log the fact that an attempted redeem
failed
            return fail(Error(error), FailureInfo.REDEEM_ACCRUE_INTEREST_FAILED);
        }
        // redeemFresh emits redeem-specific logs on errors, so we don't need to
        return redeemFresh(msg.sender, redeemTokens, 0);
    }

    /**
     * @notice Sender redeems cTokens in exchange for a specified amount of underlying asset
     * @dev Accrues interest whether or not the operation succeeds, unless reverted
     * @param redeemAmount The amount of underlying to receive from redeeming cTokens
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function redeemUnderlyingInternal(uint redeemAmount) internal nonReentrant returns (uint) {
        uint error = accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but we still want to log the fact that an attempted redeem
failed
            return fail(Error(error), FailureInfo.REDEEM_ACCRUE_INTEREST_FAILED);
        }
        // redeemFresh emits redeem-specific logs on errors, so we don't need to
        return redeemFresh(msg.sender, 0, redeemAmount);
    }

    struct RedeemLocalVars {
        Error err;
        MathError mathErr;
        uint exchangeRateMantissa;
        uint redeemTokens;
        uint redeemAmount;
        uint totalSupplyNew;
        uint accountTokensNew;
    }

    /**
     * @notice User redeems cTokens in exchange for the underlying asset
     * @dev Assumes interest has already been accrued up to the current block
     * @param redeemer The address of the account which is redeeming the tokens
     * @param redeemTokensIn The number of cTokens to redeem into underlying (only one of redeemTokensIn or redeemAmountIn may be non-zero)
     * @param redeemAmountIn The number of underlying tokens to receive from redeeming cTokens (only one of redeemTokensIn or redeemAmountIn may be non-zero)
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function redeemFresh(address payable redeemer, uint redeemTokensIn, uint redeemAmountIn) internal returns (uint) {
        require(redeemTokensIn == 0 || redeemAmountIn == 0, "one of redeemTokensIn or redeemAmountIn must be zero");

        RedeemLocalVars memory vars;

        /* exchangeRate = invoke Exchange Rate Stored() */
        (vars.mathErr, vars.exchangeRateMantissa) = exchangeRateStoredInternal();
        if (vars.mathErr != MathError.NO_ERROR) {
            return failOpaque(Error.MATH_ERROR, FailureInfo.REDEEM_EXCHANGE_RATE_READ_FAILED, uint(vars.mathErr));
        }

        /* If redeemTokensIn > 0: */
        if (redeemTokensIn > 0) {
            /*
             * We calculate the exchange rate and the amount of underlying to be redeemed:
             *  redeemTokens = redeemTokensIn
             *  redeemAmount = redeemTokensIn x exchangeRateCurrent
             */
            vars.redeemTokens = redeemTokensIn;

            (vars.mathErr, vars.redeemAmount) = mulScalarTruncate(Exp({mantissa: vars.exchangeRateMantissa}), redeemTokensIn);
            if (vars.mathErr != MathError.NO_ERROR) {
                return failOpaque(Error.MATH_ERROR, FailureInfo.REDEEM_EXCHANGE_TOKENS_CALCULATION_FAILED, uint(vars.mathErr));
            }
        } else {
            /*
             * We get the current exchange rate and calculate the amount to be redeemed:
             *  redeemTokens = redeemAmountIn / exchangeRate
             *  redeemAmount = redeemAmountIn
             */

            (vars.mathErr, vars.redeemTokens) = divScalarByExpTruncate(redeemAmountIn, Exp({mantissa: vars.exchangeRateMantissa}));
            if (vars.mathErr != MathError.NO_ERROR) {
                return failOpaque(Error.MATH_ERROR, FailureInfo.REDEEM_EXCHANGE_AMOUNT_CALCULATION_FAILED, uint(vars.mathErr));
            }

            vars.redeemAmount = redeemAmountIn;
        }

        /* Fail if redeem not allowed */
        uint allowed = comptroller.redeemAllowed(address(this), redeemer, vars.redeemTokens);
        if (allowed != 0) {
            return failOpaque(Error.ChannelsTROLLER_REJECTION, FailureInfo.REDEEM_ChannelsTROLLER_REJECTION, allowed);
        }

        /* Verify market's block number equals current block number */
        if (accrualBlockNumber != getBlockNumber()) {
            return fail(Error.MARKET_NOT_FRESH, FailureInfo.REDEEM_FRESHNESS_CHECK);
        }

        /*
         * We calculate the new total supply and redeemer balance, checking for underflow:
         *  totalSupplyNew = totalSupply - redeemTokens
         *  accountTokensNew = accountTokens[redeemer] - redeemTokens
         */
        (vars.mathErr, vars.totalSupplyNew) = subUInt(totalSupply, vars.redeemTokens);
        if (vars.mathErr != MathError.NO_ERROR) {
            return failOpaque(Error.MATH_ERROR, FailureInfo.REDEEM_NEW_TOTAL_SUPPLY_CALCULATION_FAILED, uint(vars.mathErr));
        }

        (vars.mathErr, vars.accountTokensNew) = subUInt(accountTokens[redeemer], vars.redeemTokens);
        if (vars.mathErr != MathError.NO_ERROR) {
            return failOpaque(Error.MATH_ERROR, FailureInfo.REDEEM_NEW_ACCOUNT_BALANCE_CALCULATION_FAILED, uint(vars.mathErr));
        }

        /* Fail gracefully if protocol has insufficient cash */
        if (getCashPrior() < vars.redeemAmount) {
            return                                fail(Error.TOKEN_INSUFFICIENT_CASH,
FailureInfo.REDEEM_TRANSFER_OUT_NOT_POSSIBLE);
        }

        /////////////////////////
        // EFFECTS & INTERACTIONS
        // (No safe failures beyond this point)

        /*
         * We invoke doTransferOut for the redeemer and the redeemAmount.
         *   Note: The cToken must handle variations between ERC-20 and ETH underlying.
         *   On success, the cToken has redeemAmount less of cash.
         *   doTransferOut reverts if anything goes wrong, since we can't be sure if side effects occurred.
         */
        doTransferOut(redeemer, vars.redeemAmount);

        /* We write previously calculated values into storage */
        totalSupply = vars.totalSupplyNew;
        accountTokens[redeemer] = vars.accountTokensNew;

        /* We emit a Transfer event, and a Redeem event */
        emit Transfer(redeemer, address(this), vars.redeemTokens);
        emit Redeem(redeemer, vars.redeemAmount, vars.redeemTokens);

        /* We call the defense hook */
        comptroller.redeemVerify(address(this), redeemer, vars.redeemAmount, vars.redeemTokens);

        return uint(Error.NO_ERROR);
    }

    /**
      * @notice Sender borrows assets from the protocol to their own address
      * @param borrowAmount The amount of the underlying asset to borrow
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function borrowInternal(uint borrowAmount) internal nonReentrant returns (uint) {
        uint error = accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but we still want to log the fact that an attempted borrow
failed
            return fail(Error(error), FailureInfo.BORROW_ACCRUE_INTEREST_FAILED);
        }
        // borrowFresh emits borrow-specific logs on errors, so we don't need to
        return borrowFresh(msg.sender, borrowAmount);
    }

    struct BorrowLocalVars {
        MathError mathErr;
        uint accountBorrows;
        uint accountBorrowsNew;
        uint totalBorrowsNew;
    }

    /**
      * @notice Users borrow assets from the protocol to their own address
      * @param borrowAmount The amount of the underlying asset to borrow
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function borrowFresh(address payable borrower, uint borrowAmount) internal returns (uint) {
        /* Fail if borrow not allowed */
        uint allowed = comptroller.borrowAllowed(address(this), borrower, borrowAmount);
        if (allowed != 0) {
            return                          failOpaque(Error.ChannelsTROLLER_REJECTION,
FailureInfo.BORROW_ChannelsTROLLER_REJECTION, allowed);
        }

        /* Verify market's block number equals current block number */
        if (accrualBlockNumber != getBlockNumber()) {
            return fail(Error.MARKET_NOT_FRESH, FailureInfo.BORROW_FRESHNESS_CHECK);
        }

        /* Fail gracefully if protocol has insufficient underlying cash */
        if (getCashPrior() < borrowAmount) {
            return                                fail(Error.TOKEN_INSUFFICIENT_CASH,
FailureInfo.BORROW_CASH_NOT_AVAILABLE);
        }

        BorrowLocalVars memory vars;

        /*
         * We calculate the new borrower and total borrow balances, failing on overflow:
         *   accountBorrowsNew = accountBorrows + borrowAmount
         *   totalBorrowsNew = totalBorrows + borrowAmount
         */
        (vars.mathErr, vars.accountBorrows) = borrowBalanceStoredInternal(borrower);
        if (vars.mathErr != MathError.NO_ERROR) {
            return                                                    failOpaque(Error.MATH_ERROR,
FailureInfo.BORROW_ACCUMULATED_BALANCE_CALCULATION_FAILED, uint(vars.mathErr));
        }

        (vars.mathErr, vars.accountBorrowsNew) = addUInt(vars.accountBorrows, borrowAmount);
        if (vars.mathErr != MathError.NO_ERROR) {
            return                                                    failOpaque(Error.MATH_ERROR,
FailureInfo.BORROW_NEW_ACCOUNT_BORROW_BALANCE_CALCULATION_FAILED, uint(vars.mathErr));
        }

        (vars.mathErr, vars.totalBorrowsNew) = addUInt(totalBorrows, borrowAmount);
        if (vars.mathErr != MathError.NO_ERROR) {
            return                                                    failOpaque(Error.MATH_ERROR,
FailureInfo.BORROW_NEW_TOTAL_BALANCE_CALCULATION_FAILED, uint(vars.mathErr));
        }

        /////////////////////////
        // EFFECTS & INTERACTIONS
        // (No safe failures beyond this point)

        /*
         * We invoke doTransferOut for the borrower and the borrowAmount.
         *   Note: The cToken must handle variations between ERC-20 and ETH underlying.
         *   On success, the cToken borrowAmount less of cash.
         *   doTransferOut reverts if anything goes wrong, since we can't be sure if side effects occurred.
         */
        doTransferOut(borrower, borrowAmount);

        /* We write the previously calculated values into storage */
        accountBorrows[borrower].principal = vars.accountBorrowsNew;
        accountBorrows[borrower].interestIndex = borrowIndex;
        totalBorrows = vars.totalBorrowsNew;

        /* We emit a Borrow event */
        emit Borrow(borrower, borrowAmount, vars.accountBorrowsNew, vars.totalBorrowsNew);

        /* We call the defense hook */
        comptroller.borrowVerify(address(this), borrower, borrowAmount);

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Sender repays their own borrow
     * @param repayAmount The amount to repay
     * @return (uint, uint) An error code (0=success, otherwise a failure, see ErrorReporter.sol), and the actual
repayment amount.
     */
    function repayBorrowInternal(uint repayAmount) internal nonReentrant returns (uint, uint) {
        uint error = accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but we still want to log the fact that an attempted borrow
failed
            return (fail(Error(error), FailureInfo.REPAY_BORROW_ACCRUE_INTEREST_FAILED), 0);
        }
        // repayBorrowFresh emits repay-borrow-specific logs on errors, so we don't need to
        return repayBorrowFresh(msg.sender, msg.sender, repayAmount);
    }

    /**
     * @notice Sender repays a borrow belonging to borrower
     * @param borrower the account with the debt being payed off
     * @param repayAmount The amount to repay
     * @return (uint, uint) An error code (0=success, otherwise a failure, see ErrorReporter.sol), and the actual
repayment amount.
     */
    function repayBorrowBehalfInternal(address borrower, uint repayAmount) internal nonReentrant returns
(uint, uint) {
        uint error = accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but we still want to log the fact that an attempted borrow
failed
            return (fail(Error(error), FailureInfo.REPAY_BEHALF_ACCRUE_INTEREST_FAILED), 0);
        }
        // repayBorrowFresh emits repay-borrow-specific logs on errors, so we don't need to
        return repayBorrowFresh(msg.sender, borrower, repayAmount);
    }

    struct RepayBorrowLocalVars {
        Error err;
        MathError mathErr;
        uint repayAmount;
        uint borrowerIndex;
        uint accountBorrows;
        uint accountBorrowsNew;
        uint totalBorrowsNew;
        uint actualRepayAmount;
    }

    /**
     * @notice Borrows are repaid by another user (possibly the borrower).
     * @param payer the account paying off the borrow
     * @param borrower the account with the debt being payed off
     * @param repayAmount the amount of undelrying tokens being returned
     * @return (uint, uint) An error code (0=success, otherwise a failure, see ErrorReporter.sol), and the actual
repayment amount.
     */
    function repayBorrowFresh(address payer, address borrower, uint repayAmount) internal returns (uint, uint)
{
        /* Fail if repayBorrow not allowed */
        uint allowed = comptroller.repayBorrowAllowed(address(this), payer, borrower, repayAmount);
        if (allowed != 0) {
            return                              (failOpaque(Error.ChannelsTROLLER_REJECTION,
FailureInfo.REPAY_BORROW_ChannelsTROLLER_REJECTION, allowed), 0);
        }

        /* Verify market's block number equals current block number */
        if (accrualBlockNumber != getBlockNumber()) {
            return                                          (fail(Error.MARKET_NOT_FRESH,
FailureInfo.REPAY_BORROW_FRESHNESS_CHECK), 0);
        }

        RepayBorrowLocalVars memory vars;

        /* We remember the original borrowerIndex for verification purposes */
        vars.borrowerIndex = accountBorrows[borrower].interestIndex;

        /* We fetch the amount the borrower owes, with accumulated interest */
        (vars.mathErr, vars.accountBorrows) = borrowBalanceStoredInternal(borrower);
        if (vars.mathErr != MathError.NO_ERROR) {
            return                                          (failOpaque(Error.MATH_ERROR,
FailureInfo.REPAY_BORROW_ACCUMULATED_BALANCE_CALCULATION_FAILED,     uint(vars.mathErr)),
0);
        }

        /* If repayAmount == -1, repayAmount = accountBorrows */
        if (repayAmount == uint(-1)) {
            vars.repayAmount = vars.accountBorrows;
        } else {
            vars.repayAmount = repayAmount;
        }

        /////////////////////////
        // EFFECTS & INTERACTIONS
        // (No safe failures beyond this point)

        /*
         * We call doTransferIn for the payer and the repayAmount
         *   Note: The cToken must handle variations between ERC-20 and ETH underlying.
         *   On success, the cToken holds an additional repayAmount of cash.
         *   doTransferIn reverts if anything goes wrong, since we can't be sure if side effects occurred.
         *    it returns the amount actually transferred, in case of a fee.
         */
        vars.actualRepayAmount = doTransferIn(payer, vars.repayAmount);

        /*
         * We calculate the new borrower and total borrow balances, failing on underflow:
         *   accountBorrowsNew = accountBorrows - actualRepayAmount
         *   totalBorrowsNew = totalBorrows - actualRepayAmount
         */
        (vars.mathErr, vars.accountBorrowsNew) = subUInt(vars.accountBorrows, vars.actualRepayAmount);
        require(vars.mathErr                    ==                    MathError.NO_ERROR,
"REPAY_BORROW_NEW_ACCOUNT_BORROW_BALANCE_CALCULATION_FAILED");

        (vars.mathErr, vars.totalBorrowsNew) = subUInt(totalBorrows, vars.actualRepayAmount);
        require(vars.mathErr                    ==                    MathError.NO_ERROR,
"REPAY_BORROW_NEW_TOTAL_BALANCE_CALCULATION_FAILED");

        /* We write the previously calculated values into storage */
        accountBorrows[borrower].principal = vars.accountBorrowsNew;
        accountBorrows[borrower].interestIndex = borrowIndex;
        totalBorrows = vars.totalBorrowsNew;

        /* We emit a RepayBorrow event */
        emit    RepayBorrow(payer,    borrower,    vars.actualRepayAmount,    vars.accountBorrowsNew,
vars.totalBorrowsNew);

        /* We call the defense hook */
        comptroller.repayBorrowVerify(address(this),    payer,    borrower,    vars.actualRepayAmount,
vars.borrowerIndex);
```

```
        return (uint(Error.NO_ERROR), vars.actualRepayAmount);
    }

    /**
     * @notice The sender liquidates the borrowers collateral.
     *  The collateral seized is transferred to the liquidator.
     * @param borrower The borrower of this cToken to be liquidated
     * @param cTokenCollateral The market in which to seize collateral from the borrower
     * @param repayAmount The amount of the underlying borrowed asset to repay
     * @return (uint, uint) An error code (0=success, otherwise a failure, see ErrorReporter.sol), and the actual
repayment amount.
     */
    function liquidateBorrowInternal(address borrower, uint repayAmount, CTokenInterface cTokenCollateral)
internal nonReentrant returns (uint, uint) {
        uint error = accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but we still want to log the fact that an attempted liquidation
failed
            return (fail(Error(error), FailureInfo.LIQUIDATE_ACCRUE_BORROW_INTEREST_FAILED),
0);
        }

        error = cTokenCollateral.accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but we still want to log the fact that an attempted liquidation
failed
            return                                                            (fail(Error(error),
FailureInfo.LIQUIDATE_ACCRUE_COLLATERAL_INTEREST_FAILED), 0);
        }

        // liquidateBorrowFresh emits borrow-specific logs on errors, so we don't need to
        return liquidateBorrowFresh(msg.sender, borrower, repayAmount, cTokenCollateral);
    }

    /**
     * @notice The liquidator liquidates the borrowers collateral.
     *  The collateral seized is transferred to the liquidator.
     * @param borrower The borrower of this cToken to be liquidated
     * @param liquidator The address repaying the borrow and seizing collateral
     * @param cTokenCollateral The market in which to seize collateral from the borrower
     * @param repayAmount The amount of the underlying borrowed asset to repay
     * @return (uint, uint) An error code (0=success, otherwise a failure, see ErrorReporter.sol), and the actual
repayment amount.
     */
    function liquidateBorrowFresh(address liquidator, address borrower, uint repayAmount, CTokenInterface
cTokenCollateral) internal returns (uint, uint) {
        /* Fail if liquidate not allowed */
        uint allowed = comptroller.liquidateBorrowAllowed(address(this), address(cTokenCollateral),
liquidator, borrower, repayAmount);
        if (allowed != 0) {
            return                         (failOpaque(Error.ChannelsTROLLER_REJECTION,
FailureInfo.LIQUIDATE_ChannelsTROLLER_REJECTION, allowed), 0);
        }

        /* Verify market's block number equals current block number */
        if (accrualBlockNumber != getBlockNumber()) {
            return (fail(Error.MARKET_NOT_FRESH, FailureInfo.LIQUIDATE_FRESHNESS_CHECK), 0);
        }

        /* Verify cTokenCollateral market's block number equals current block number */
        if (cTokenCollateral.accrualBlockNumber() != getBlockNumber()) {
            return                                          (fail(Error.MARKET_NOT_FRESH,
FailureInfo.LIQUIDATE_COLLATERAL_FRESHNESS_CHECK), 0);
        }

        /* Fail if borrower = liquidator */
        if (borrower == liquidator) {
            return                                        (fail(Error.INVALID_ACCOUNT_PAIR,
FailureInfo.LIQUIDATE_LIQUIDATOR_IS_BORROWER), 0);
        }

        /* Fail if repayAmount = 0 */
        if (repayAmount == 0) {
            return                         (fail(Error.INVALID_CLOSE_AMOUNT_REQUESTED,
FailureInfo.LIQUIDATE_CLOSE_AMOUNT_IS_ZERO), 0);
        }

        /* Fail if repayAmount = -1 */
        if (repayAmount == uint(-1)) {
            return                         (fail(Error.INVALID_CLOSE_AMOUNT_REQUESTED,
FailureInfo.LIQUIDATE_CLOSE_AMOUNT_IS_UINT_MAX), 0);
        }


        /* Fail if repayBorrow fails */
        (uint repayBorrowError, uint actualRepayAmount) = repayBorrowFresh(liquidator, borrower,
repayAmount);
```

```
        if (repayBorrowError != uint(Error.NO_ERROR)) {
            return (fail(Error(repayBorrowError), FailureInfo.LIQUIDATE_REPAY_BORROW_FRESH_FAILED), 0);
        }

        /////////////////////////
        // EFFECTS & INTERACTIONS
        // (No safe failures beyond this point)

        /* We calculate the number of collateral tokens that will be seized */
        (uint amountSeizeError, uint seizeTokens) = comptroller.liquidateCalculateSeizeTokens(address(this), address(cTokenCollateral), actualRepayAmount);
        require(amountSeizeError == uint(Error.NO_ERROR), "LIQUIDATE_ChannelsTROLLER_CALCULATE_AMOUNT_SEIZE_FAILED");

        /* Revert if borrower collateral token balance < seizeTokens */
        require(cTokenCollateral.balanceOf(borrower) >= seizeTokens, "LIQUIDATE_SEIZE_TOO_MUCH");

        // If this is also the collateral, run seizeInternal to avoid re-entrancy, otherwise make an external call
        uint seizeError;
        if (address(cTokenCollateral) == address(this)) {
            seizeError = seizeInternal(address(this), liquidator, borrower, seizeTokens);
        } else {
            seizeError = cTokenCollateral.seize(liquidator, borrower, seizeTokens);
        }

        /* Revert if seize tokens fails (since we cannot be sure of side effects) */
        require(seizeError == uint(Error.NO_ERROR), "token seizure failed");

        /* We emit a LiquidateBorrow event */
        emit LiquidateBorrow(liquidator, borrower, actualRepayAmount, address(cTokenCollateral), seizeTokens);

        /* We call the defense hook */
        comptroller.liquidateBorrowVerify(address(this), address(cTokenCollateral), liquidator, borrower, actualRepayAmount, seizeTokens);

        return (uint(Error.NO_ERROR), actualRepayAmount);
    }

    /**
     * @notice Transfers collateral tokens (this market) to the liquidator.
     * @dev Will fail unless called by another cToken during the process of liquidation.
     *   Its absolutely critical to use msg.sender as the borrowed cToken and not a parameter.
     * @param liquidator The account receiving seized collateral
     * @param borrower The account having collateral seized
     * @param seizeTokens The number of cTokens to seize
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function seize(address liquidator, address borrower, uint seizeTokens) external nonReentrant returns (uint) {
        return seizeInternal(msg.sender, liquidator, borrower, seizeTokens);
    }

    /**
     * @notice Transfers collateral tokens (this market) to the liquidator.
     * @dev Called only during an in-kind liquidation, or by liquidateBorrow during the liquidation of another CToken.
     *   Its absolutely critical to use msg.sender as the seizer cToken and not a parameter.
     * @param seizerToken The contract seizing the collateral (i.e. borrowed cToken)
     * @param liquidator The account receiving seized collateral
     * @param borrower The account having collateral seized
     * @param seizeTokens The number of cTokens to seize
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function seizeInternal(address seizerToken, address liquidator, address borrower, uint seizeTokens) internal returns (uint) {
        /* Fail if seize not allowed */
        uint allowed = comptroller.seizeAllowed(address(this), seizerToken, liquidator, borrower, seizeTokens);
        if (allowed != 0) {
            return failOpaque(Error.ChannelsTROLLER_REJECTION, FailureInfo.LIQUIDATE_SEIZE_ChannelsTROLLER_REJECTION, allowed);
        }

        /* Fail if borrower = liquidator */
        if (borrower == liquidator) {
            return fail(Error.INVALID_ACCOUNT_PAIR, FailureInfo.LIQUIDATE_SEIZE_LIQUIDATOR_IS_BORROWER);
        }

        MathError mathErr;
        uint borrowerTokensNew;
        uint liquidatorTokensNew;

        /*
         * We calculate the new borrower and liquidator token balances, failing on underflow/overflow:
         *   borrowerTokensNew = accountTokens[borrower] - seizeTokens
         *   liquidatorTokensNew = accountTokens[liquidator] + seizeTokens
         */
        (mathErr, borrowerTokensNew) = subUInt(accountTokens[borrower], seizeTokens);
        if (mathErr != MathError.NO_ERROR) {
            return                                                    failOpaque(Error.MATH_ERROR,
FailureInfo.LIQUIDATE_SEIZE_BALANCE_DECREMENT_FAILED, uint(mathErr));
        }

        (mathErr, liquidatorTokensNew) = addUInt(accountTokens[liquidator], seizeTokens);
        if (mathErr != MathError.NO_ERROR) {
            return                                                    failOpaque(Error.MATH_ERROR,
FailureInfo.LIQUIDATE_SEIZE_BALANCE_INCREMENT_FAILED, uint(mathErr));
        }

        /////////////////////////
        // EFFECTS & INTERACTIONS
        // (No safe failures beyond this point)

        /* We write the previously calculated values into storage */
        accountTokens[borrower] = borrowerTokensNew;
        accountTokens[liquidator] = liquidatorTokensNew;

        /* Emit a Transfer event */
        emit Transfer(borrower, liquidator, seizeTokens);

        /* We call the defense hook */
        comptroller.seizeVerify(address(this), seizerToken, liquidator, borrower, seizeTokens);

        return uint(Error.NO_ERROR);
    }


    /*** Admin Functions ***/

    /**
      * @notice Begins transfer of admin rights. The newPendingAdmin must call `_acceptAdmin` to finalize the
transfer.
      * @dev Admin function to begin change of admin. The newPendingAdmin must call `_acceptAdmin` to
finalize the transfer.
      * @param newPendingAdmin New pending admin.
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _setPendingAdmin(address payable newPendingAdmin) external returns (uint) {
        // Check caller = admin
        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.SET_PENDING_ADMIN_OWNER_CHECK);
        }

        // Save current value, if any, for inclusion in log
        address oldPendingAdmin = pendingAdmin;

        // Store pendingAdmin with value newPendingAdmin
        pendingAdmin = newPendingAdmin;

        // Emit NewPendingAdmin(oldPendingAdmin, newPendingAdmin)
        emit NewPendingAdmin(oldPendingAdmin, newPendingAdmin);

        return uint(Error.NO_ERROR);
    }

    /**
      * @notice Accepts transfer of admin rights. msg.sender must be pendingAdmin
      * @dev Admin function for pending admin to accept role and update admin
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _acceptAdmin() external returns (uint) {
        // Check caller is pendingAdmin and pendingAdmin ≠ address(0)
        if (msg.sender != pendingAdmin || msg.sender == address(0)) {
            return                                                    fail(Error.UNAUTHORIZED,
FailureInfo.ACCEPT_ADMIN_PENDING_ADMIN_CHECK);
        }

        // Save current values for inclusion in log
        address oldAdmin = admin;
        address oldPendingAdmin = pendingAdmin;

        // Store admin with value pendingAdmin
        admin = pendingAdmin;

        // Clear the pending value
        pendingAdmin = address(0);

        emit NewAdmin(oldAdmin, admin);
        emit NewPendingAdmin(oldPendingAdmin, pendingAdmin);

        return uint(Error.NO_ERROR);
    }
    /**
      * @notice Sets a new comptroller for the market
      * @dev Admin function to set a new comptroller
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _setComptroller(ComptrollerInterface newComptroller) public returns (uint) {
        // Check caller is admin
        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.SET_ChannelsTROLLER_OWNER_CHECK);
        }

        ComptrollerInterface oldComptroller = comptroller;
        // Ensure invoke comptroller.isComptroller() returns true
        require(newComptroller.isComptroller(), "marker method returned false");

        // Set market's comptroller to newComptroller
        comptroller = newComptroller;

        // Emit NewComptroller(oldComptroller, newComptroller)
        emit NewComptroller(oldComptroller, newComptroller);

        return uint(Error.NO_ERROR);
    }

    /**
      * @notice accrues interest and sets a new reserve factor for the protocol using _setReserveFactorFresh
      * @dev Admin function to accrue interest and set a new reserve factor
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _setReserveFactor(uint newReserveFactorMantissa) external nonReentrant returns (uint) {
        uint error = accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but on top of that we want to log the fact that an attempted
reserve factor change failed.
            return fail(Error(error), FailureInfo.SET_RESERVE_FACTOR_ACCRUE_INTEREST_FAILED);
        }
        // _setReserveFactorFresh emits reserve-factor-specific logs on errors, so we don't need to.
        return _setReserveFactorFresh(newReserveFactorMantissa);
    }

    /**
      * @notice Sets a new reserve factor for the protocol (*requires fresh interest accrual)
      * @dev Admin function to set a new reserve factor
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _setReserveFactorFresh(uint newReserveFactorMantissa) internal returns (uint) {
        // Check caller is admin
        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.SET_RESERVE_FACTOR_ADMIN_CHECK);
        }

        // Verify market's block number equals current block number
        if (accrualBlockNumber != getBlockNumber()) {
            return                                            fail(Error.MARKET_NOT_FRESH,
FailureInfo.SET_RESERVE_FACTOR_FRESH_CHECK);
        }

        // Check newReserveFactor ≤ maxReserveFactor
        if (newReserveFactorMantissa > reserveFactorMaxMantissa) {
            return fail(Error.BAD_INPUT, FailureInfo.SET_RESERVE_FACTOR_BOUNDS_CHECK);
        }

        uint oldReserveFactorMantissa = reserveFactorMantissa;
        reserveFactorMantissa = newReserveFactorMantissa;

        emit NewReserveFactor(oldReserveFactorMantissa, newReserveFactorMantissa);

        return uint(Error.NO_ERROR);
    }

    /**
     * @notice Accrues interest and reduces reserves by transferring from msg.sender
     * @param addAmount Amount of addition to reserves
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function _addReservesInternal(uint addAmount) internal nonReentrant returns (uint) {
        uint error = accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but on top of that we want to log the fact that an attempted
reduce reserves failed.
            return fail(Error(error), FailureInfo.ADD_RESERVES_ACCRUE_INTEREST_FAILED);
        }

        // _addReservesFresh emits reserve-addition-specific logs on errors, so we don't need to.
        (error, ) = _addReservesFresh(addAmount);
        return error;
    }
    /**
     * @notice Add reserves by transferring from caller
     * @dev Requires fresh interest accrual
     * @param addAmount Amount of addition to reserves
     * @return (uint, uint) An error code (0=success, otherwise a failure (see ErrorReporter.sol for details)) and
the actual amount added, net token fees
     */
    function _addReservesFresh(uint addAmount) internal returns (uint, uint) {
        // totalReserves + actualAddAmount
        uint totalReservesNew;
        uint actualAddAmount;

        // We fail gracefully unless market's block number equals current block number
        if (accrualBlockNumber != getBlockNumber()) {
            return    (fail(Error.MARKET_NOT_FRESH,    FailureInfo.ADD_RESERVES_FRESH_CHECK),
actualAddAmount);
        }

        /////////////////////////
        // EFFECTS & INTERACTIONS
        // (No safe failures beyond this point)

        /*
         * We call doTransferIn for the caller and the addAmount
         *   Note: The cToken must handle variations between ERC-20 and ETH underlying.
         *   On success, the cToken holds an additional addAmount of cash.
         *   doTransferIn reverts if anything goes wrong, since we can't be sure if side effects occurred.
         *   it returns the amount actually transferred, in case of a fee.
         */

        actualAddAmount = doTransferIn(msg.sender, addAmount);

        totalReservesNew = totalReserves + actualAddAmount;

        /* Revert on overflow */
        require(totalReservesNew >= totalReserves, "add reserves unexpected overflow");

        // Store reserves[n+1] = reserves[n] + actualAddAmount
        totalReserves = totalReservesNew;

        /* Emit NewReserves(admin, actualAddAmount, reserves[n+1]) */
        emit ReservesAdded(msg.sender, actualAddAmount, totalReservesNew);

        /* Return (NO_ERROR, actualAddAmount) */
        return (uint(Error.NO_ERROR), actualAddAmount);
    }


    /**
     * @notice Accrues interest and reduces reserves by transferring to admin
     * @param reduceAmount Amount of reduction to reserves
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function _reduceReserves(uint reduceAmount) external nonReentrant returns (uint) {
        uint error = accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but on top of that we want to log the fact that an attempted
reduce reserves failed.
            return fail(Error(error), FailureInfo.REDUCE_RESERVES_ACCRUE_INTEREST_FAILED);
        }
        // _reduceReservesFresh emits reserve-reduction-specific logs on errors, so we don't need to.
        return _reduceReservesFresh(reduceAmount);
    }

    /**
     * @notice Reduces reserves by transferring to admin
     * @dev Requires fresh interest accrual
     * @param reduceAmount Amount of reduction to reserves
     * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
     */
    function _reduceReservesFresh(uint reduceAmount) internal returns (uint) {
        // totalReserves - reduceAmount
        uint totalReservesNew;

        // Check caller is admin
        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.REDUCE_RESERVES_ADMIN_CHECK);
        }

        // We fail gracefully unless market's block number equals current block number
        if (accrualBlockNumber != getBlockNumber()) {
            return fail(Error.MARKET_NOT_FRESH, FailureInfo.REDUCE_RESERVES_FRESH_CHECK);
        }

        // Fail gracefully if protocol has insufficient underlying cash
        if (getCashPrior() < reduceAmount) {
            return fail(Error.TOKEN_INSUFFICIENT_CASH, FailureInfo.REDUCE_RESERVES_CASH_NOT_AVAILABLE);
        }

        // Check reduceAmount ≤ reserves[n] (totalReserves)
        if (reduceAmount > totalReserves) {
            return fail(Error.BAD_INPUT, FailureInfo.REDUCE_RESERVES_VALIDATION);
        }

        /////////////////////////
        // EFFECTS & INTERACTIONS
        // (No safe failures beyond this point)

        totalReservesNew = totalReserves - reduceAmount;
        // We checked reduceAmount <= totalReserves above, so this should never revert.
        require(totalReservesNew <= totalReserves, "reduce reserves unexpected underflow");

        // Store reserves[n+1] = reserves[n] - reduceAmount
        totalReserves = totalReservesNew;

        // doTransferOut reverts if anything goes wrong, since we can't be sure if side effects occurred.
        doTransferOut(admin, reduceAmount);

        emit ReservesReduced(admin, reduceAmount, totalReservesNew);

        return uint(Error.NO_ERROR);
    }

    /**
      * @notice accrues interest and updates the interest rate model using _setInterestRateModelFresh
      * @dev Admin function to accrue interest and update the interest rate model
      * @param newInterestRateModel the new interest rate model to use
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _setInterestRateModel(InterestRateModel newInterestRateModel) public returns (uint) {
        uint error = accrueInterest();
        if (error != uint(Error.NO_ERROR)) {
            // accrueInterest emits logs on errors, but on top of that we want to log the fact that an attempted change of interest rate model failed
            return fail(Error(error), FailureInfo.SET_INTEREST_RATE_MODEL_ACCRUE_INTEREST_FAILED);
        }
        // _setInterestRateModelFresh emits interest-rate-model-update-specific logs on errors, so we don't need to.
        return _setInterestRateModelFresh(newInterestRateModel);
    }

    /**
      * @notice updates the interest rate model (*requires fresh interest accrual)
      * @dev Admin function to update the interest rate model
      * @param newInterestRateModel the new interest rate model to use
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _setInterestRateModelFresh(InterestRateModel newInterestRateModel) internal returns (uint) {

        // Used to store old model for use in the event that is emitted on success
        InterestRateModel oldInterestRateModel;

        // Check caller is admin
        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.SET_INTEREST_RATE_MODEL_OWNER_CHECK);
        }

        // We fail gracefully unless market's block number equals current block number
        if (accrualBlockNumber != getBlockNumber()) {
            return fail(Error.MARKET_NOT_FRESH, FailureInfo.SET_INTEREST_RATE_MODEL_FRESH_CHECK);
        }

        // Track the market's current interest rate model
        oldInterestRateModel = interestRateModel;

        // Ensure invoke newInterestRateModel.isInterestRateModel() returns true
        require(newInterestRateModel.isInterestRateModel(), "marker method returned false");

        // Set the interest rate model to newInterestRateModel
        interestRateModel = newInterestRateModel;

        // Emit NewMarketInterestRateModel(oldInterestRateModel, newInterestRateModel)
        emit NewMarketInterestRateModel(oldInterestRateModel, newInterestRateModel);

        return uint(Error.NO_ERROR);
    }

    /*** Safe Token ***/
    /**
     * @notice Gets balance of this contract in terms of the underlying
     * @dev This excludes the value of the current message, if any
     * @return The quantity of underlying owned by this contract
     */
    function getCashPrior() internal view returns (uint);

    /**
     * @dev Performs a transfer in, reverting upon failure. Returns the amount actually transferred to the
protocol, in case of a fee.
     *   This may revert due to insufficient balance or insufficient allowance.
     */
    function doTransferIn(address from, uint amount) internal returns (uint);

    /**
     * @dev Performs a transfer out, ideally returning an explanatory error code upon failure tather than
reverting.
     *   If caller has not called checked protocol's balance, may revert due to insufficient cash held in the
contract.
     *   If caller has checked protocol's balance, and verified it is >= amount, this should not revert in normal
conditions.
     */
    function doTransferOut(address payable to, uint amount) internal;


    /*** Reentrancy Guard ***/

    /**
     * @dev Prevents a contract from calling itself, directly or indirectly.
     */
    modifier nonReentrant() {
        require(_notEntered, "re-entered");
        _notEntered = false;
        _;
        _notEntered = true; // get a gas-refund post-Istanbul
    }
}
```

CTokenInterfaces.sol

```
pragma solidity ^0.5.16;

import "./ComptrollerInterface.sol";
import "./InterestRateModel.sol";

contract CTokenStorage {
    /**
     * @dev Guard variable for re-entrancy checks
     */
    bool internal _notEntered;

    /**
     * @notice EIP-20 token name for this token
     */
    string public name;

    /**
     * @notice EIP-20 token symbol for this token
     */
    string public symbol;

    /**
     * @notice EIP-20 token decimals for this token
     */
    uint8 public decimals;

    /**
     * @notice Maximum borrow rate that can ever be applied (.0005% / block)
     */

    uint internal constant borrowRateMaxMantissa = 0.0005e16;

    /**
     * @notice Maximum fraction of interest that can be set aside for reserves
     */
    uint internal constant reserveFactorMaxMantissa = 1e18;

    /**
     * @notice Administrator for this contract
     */
    address payable public admin;

    /**
     * @notice Pending administrator for this contract
     */
    address payable public pendingAdmin;
    /**
     * @notice Contract which oversees inter-cToken operations
     */
    ComptrollerInterface public comptroller;

    /**
     * @notice Model which tells what the current interest rate should be
     */
    InterestRateModel public interestRateModel;

    /**
     * @notice Initial exchange rate used when minting the first CTokens (used when totalSupply = 0)
     */
    uint internal initialExchangeRateMantissa;

    /**
     * @notice Fraction of interest currently set aside for reserves
     */
    uint public reserveFactorMantissa;

    /**
     * @notice Block number that interest was last accrued at
     */
    uint public accrualBlockNumber;

    /**
     * @notice Accumulator of the total earned interest rate since the opening of the market
     */
    uint public borrowIndex;

    /**
     * @notice Total amount of outstanding borrows of the underlying in this market
     */
    uint public totalBorrows;

    /**
     * @notice Total amount of reserves of the underlying held in this market
     */
    uint public totalReserves;

    /**
     * @notice Total number of tokens in circulation
     */
    uint public totalSupply;

    /**
     * @notice Official record of token balances for each account
     */
    mapping (address => uint) internal accountTokens;

    /**
     * @notice Approved token transfer amounts on behalf of others
     */
    mapping (address => mapping (address => uint)) internal transferAllowances;

    /**
     * @notice Container for borrow balance information
     * @member principal Total balance (with accrued interest), after applying the most recent
balance-changing action
     * @member interestIndex Global borrowIndex as of the most recent balance-changing action
     */
    struct BorrowSnapshot {
        uint principal;
        uint interestIndex;
    }

    /**
     * @notice Mapping of account addresses to outstanding borrow balances
     */
    mapping(address => BorrowSnapshot) internal accountBorrows;
}

contract CTokenInterface is CTokenStorage {
    /**
     * @notice Indicator that this is a CToken contract (for inspection)
     */
    bool public constant isCToken = true;


    /*** Market Events ***/

    /**
     * @notice Event emitted when interest is accrued
     */
    event AccrueInterest(uint cashPrior, uint interestAccumulated, uint borrowIndex, uint totalBorrows);
    /**
     * @notice Event emitted when tokens are minted
     */
    event Mint(address minter, uint mintAmount, uint mintTokens);

    /**
     * @notice Event emitted when tokens are redeemed
     */
    event Redeem(address redeemer, uint redeemAmount, uint redeemTokens);

    /**
     * @notice Event emitted when underlying is borrowed
     */
    event Borrow(address borrower, uint borrowAmount, uint accountBorrows, uint totalBorrows);

    /**
     * @notice Event emitted when a borrow is repaid
     */
    event RepayBorrow(address payer, address borrower, uint repayAmount, uint accountBorrows, uint
totalBorrows);

    /**
     * @notice Event emitted when a borrow is liquidated
     */
    event LiquidateBorrow(address liquidator, address borrower, uint repayAmount, address cTokenCollateral,
uint seizeTokens);


    /*** Admin Events ***/

    /**
     * @notice Event emitted when pendingAdmin is changed
     */
    event NewPendingAdmin(address oldPendingAdmin, address newPendingAdmin);

    /**
     * @notice Event emitted when pendingAdmin is accepted, which means admin is updated
     */
    event NewAdmin(address oldAdmin, address newAdmin);

    /**
     * @notice Event emitted when comptroller is changed
     */
    event NewComptroller(ComptrollerInterface oldComptroller, ComptrollerInterface newComptroller);

    /**
     * @notice Event emitted when interestRateModel is changed
     */
    event NewMarketInterestRateModel(InterestRateModel oldInterestRateModel, InterestRateModel
newInterestRateModel);

    /**
     * @notice Event emitted when the reserve factor is changed
     */
    event NewReserveFactor(uint oldReserveFactorMantissa, uint newReserveFactorMantissa);

    /**
     * @notice Event emitted when the reserves are added
     */
    event ReservesAdded(address benefactor, uint addAmount, uint newTotalReserves);

    /**
     * @notice Event emitted when the reserves are reduced
     */
    event ReservesReduced(address admin, uint reduceAmount, uint newTotalReserves);

    /**
     * @notice EIP20 Transfer event
     */
    event Transfer(address indexed from, address indexed to, uint amount);

    /**
     * @notice EIP20 Approval event
     */
    event Approval(address indexed owner, address indexed spender, uint amount);

    /**
     * @notice Failure event
     */
    event Failure(uint error, uint info, uint detail);


    /*** User Interface ***/

    function transfer(address dst, uint amount) external returns (bool);
    function transferFrom(address src, address dst, uint amount) external returns (bool);
    function approve(address spender, uint amount) external returns (bool);
    function allowance(address owner, address spender) external view returns (uint);
    function balanceOf(address owner) external view returns (uint);
    function balanceOfUnderlying(address owner) external returns (uint);
    function getAccountSnapshot(address account) external view returns (uint, uint, uint, uint);
    function borrowRatePerBlock() external view returns (uint);
    function supplyRatePerBlock() external view returns (uint);
    function totalBorrowsCurrent() external returns (uint);
    function borrowBalanceCurrent(address account) external returns (uint);
    function borrowBalanceStored(address account) public view returns (uint);
    function exchangeRateCurrent() public returns (uint);
    function exchangeRateStored() public view returns (uint);
    function getCash() external view returns (uint);
    function accrueInterest() public returns (uint);
    function seize(address liquidator, address borrower, uint seizeTokens) external returns (uint);


    /*** Admin Functions ***/

    function _setPendingAdmin(address payable newPendingAdmin) external returns (uint);
    function _acceptAdmin() external returns (uint);
    function _setComptroller(ComptrollerInterface newComptroller) public returns (uint);
    function _setReserveFactor(uint newReserveFactorMantissa) external returns (uint);
    function _reduceReserves(uint reduceAmount) external returns (uint);
    function _setInterestRateModel(InterestRateModel newInterestRateModel) public returns (uint);
}

contract CErc20Storage {
    /**
     * @notice Underlying asset for this CToken
     */
    address public underlying;
}

contract CErc20Interface is CErc20Storage {

    /*** User Interface ***/

    function mint(uint mintAmount) external returns (uint);
    function redeem(uint redeemTokens) external returns (uint);
    function redeemUnderlying(uint redeemAmount) external returns (uint);
    function borrow(uint borrowAmount) external returns (uint);
    function repayBorrow(uint repayAmount) external returns (uint);
    function repayBorrowBehalf(address borrower, uint repayAmount) external returns (uint);
    function liquidateBorrow(address borrower, uint repayAmount, CTokenInterface cTokenCollateral) external
returns (uint);


    /*** Admin Functions ***/

    function _addReserves(uint addAmount) external returns (uint);
}

contract CDelegationStorage {
    /**
     * @notice Implementation address for this contract
     */
    address public implementation;
}

contract CDelegatorInterface is CDelegationStorage {
    /**
     * @notice Emitted when implementation is changed
     */
    event NewImplementation(address oldImplementation, address newImplementation);

    /**
     * @notice Called by the admin to update the implementation of the delegator
     * @param implementation_ The address of the new implementation for delegation
     * @param allowResign Flag to indicate whether to call _resignImplementation on the old implementation
     * @param becomeImplementationData The encoded bytes data to be passed to _becomeImplementation
     */
    function    _setImplementation(address    implementation_,    bool    allowResign,    bytes    memory
becomeImplementationData) public;
}

contract CDelegateInterface is CDelegationStorage {
    /**
     * @notice Called by the delegator on a delegate to initialize it for duty
     * @dev Should revert if any issues arise which make it unfit for delegation
     * @param data The encoded bytes data for any initialization
     */
    function _becomeImplementation(bytes memory data) public;

    /**
     * @notice Called by the delegator on a delegate to forfeit its responsibility
     */
    function _resignImplementation() public;
```

```
}
```

EIP20Interface.sol

```
pragma solidity ^0.5.16;

/**
 * @title ERC 20 Token Standard Interface
 *  https://eips.ethereum.org/EIPS/eip-20
 */
interface EIP20Interface {
    function name() external view returns (string memory);
    function symbol() external view returns (string memory);
    function decimals() external view returns (uint8);

    /**
      * @notice Get the total number of tokens in circulation
      * @return The supply of tokens
      */
    function totalSupply() external view returns (uint256);

    /**
     * @notice Gets the balance of the specified address
     * @param owner The address from which the balance will be retrieved
     * @return The balance
     */
    function balanceOf(address owner) external view returns (uint256 balance);

    /**
      * @notice Transfer `amount` tokens from `msg.sender` to `dst`
      * @param dst The address of the destination account
      * @param amount The number of tokens to transfer
      * @return Whether or not the transfer succeeded
      */
    function transfer(address dst, uint256 amount) external returns (bool success);

    /**
      * @notice Transfer `amount` tokens from `src` to `dst`
      * @param src The address of the source account
      * @param dst The address of the destination account
      * @param amount The number of tokens to transfer
      * @return Whether or not the transfer succeeded
      */
    function transferFrom(address src, address dst, uint256 amount) external returns (bool success);

    /**
      * @notice Approve `spender` to transfer up to `amount` from `src`
      * @dev This will overwrite the approval amount for `spender`
      *  and is subject to issues noted [here](https://eips.ethereum.org/EIPS/eip-20#approve)
      * @param spender The address of the account which may transfer tokens
      * @param amount The number of tokens that are approved (-1 means infinite)
      * @return Whether or not the approval succeeded
      */
    function approve(address spender, uint256 amount) external returns (bool success);

    /**
      * @notice Get the current allowance from `owner` for `spender`
      * @param owner The address of the account which owns the tokens to be spent
      * @param spender The address of the account which may transfer tokens
      * @return The number of tokens allowed to be spent (-1 means infinite)
      */
    function allowance(address owner, address spender) external view returns (uint256 remaining);

    event Transfer(address indexed from, address indexed to, uint256 amount);
    event Approval(address indexed owner, address indexed spender, uint256 amount);
}
```

EIP20NonStandardInterface.sol

```
pragma solidity ^0.5.16;

/**
 * @title EIP20NonStandardInterface
 * @dev Version of ERC20 with no return values for `transfer` and `transferFrom`
 *  See https://medium.com/coinmonks/missing-return-value-bug-at-least-130-tokens-affected-d67bf08521ca
 */
interface EIP20NonStandardInterface {

    /**
     * @notice Get the total number of tokens in circulation
     * @return The supply of tokens
     */
    function totalSupply() external view returns (uint256);

    /**
     * @notice Gets the balance of the specified address
     * @param owner The address from which the balance will be retrieved
     * @return The balance
     */
    function balanceOf(address owner) external view returns (uint256 balance);

    ///
    /// !!!!!!!!!!!!!!
    /// !!! NOTICE !!! `transfer` does not return a value, in violation of the ERC-20 specification
    /// !!!!!!!!!!!!!!
    ///

    /**
      * @notice Transfer `amount` tokens from `msg.sender` to `dst`
      * @param dst The address of the destination account
      * @param amount The number of tokens to transfer
      */
    function transfer(address dst, uint256 amount) external;

    ///
    /// !!!!!!!!!!!!!!
    /// !!! NOTICE !!! `transferFrom` does not return a value, in violation of the ERC-20 specification
    /// !!!!!!!!!!!!!!
    ///

    /**
      * @notice Transfer `amount` tokens from `src` to `dst`
      * @param src The address of the source account
      * @param dst The address of the destination account
      * @param amount The number of tokens to transfer
      */
    function transferFrom(address src, address dst, uint256 amount) external;

    /**
      * @notice Approve `spender` to transfer up to `amount` from `src`
      * @dev This will overwrite the approval amount for `spender`
      *   and is subject to issues noted [here](https://eips.ethereum.org/EIPS/eip-20#approve)
      * @param spender The address of the account which may transfer tokens
      * @param amount The number of tokens that are approved
      * @return Whether or not the approval succeeded
      */
    function approve(address spender, uint256 amount) external returns (bool success);

    /**
      * @notice Get the current allowance from `owner` for `spender`
      * @param owner The address of the account which owns the tokens to be spent
      * @param spender The address of the account which may transfer tokens
      * @return The number of tokens allowed to be spent
      */
    function allowance(address owner, address spender) external view returns (uint256 remaining);

    event Transfer(address indexed from, address indexed to, uint256 amount);
    event Approval(address indexed owner, address indexed spender, uint256 amount);
}
```

ErrorReporter.sol

```
pragma solidity ^0.5.16;

contract ComptrollerErrorReporter {
    enum Error {
        NO_ERROR,
        UNAUTHORIZED,
        ChannelsTROLLER_MISMATCH,
        INSUFFICIENT_SHORTFALL,
        INSUFFICIENT_LIQUIDITY,
        INVALID_CLOSE_FACTOR,
        INVALID_COLLATERAL_FACTOR,
        INVALID_LIQUIDATION_INCENTIVE,
        MARKET_NOT_ENTERED, // no longer possible
        MARKET_NOT_LISTED,
        MARKET_ALREADY_LISTED,
        MATH_ERROR,
        NONZERO_BORROW_BALANCE,
        PRICE_ERROR,
        REJECTION,
        SNAPSHOT_ERROR,
        TOO_MANY_ASSETS,
        TOO_MUCH_REPAY
    }

    enum FailureInfo {
        ACCEPT_ADMIN_PENDING_ADMIN_CHECK,
        ACCEPT_PENDING_IMPLEMENTATION_ADDRESS_CHECK,
        EXIT_MARKET_BALANCE_OWED,
        EXIT_MARKET_REJECTION,
        SET_CLOSE_FACTOR_OWNER_CHECK,
        SET_CLOSE_FACTOR_VALIDATION,
            SET_COLLATERAL_FACTOR_OWNER_CHECK,
            SET_COLLATERAL_FACTOR_NO_EXISTS,
            SET_COLLATERAL_FACTOR_VALIDATION,
            SET_COLLATERAL_FACTOR_WITHOUT_PRICE,
            SET_IMPLEMENTATION_OWNER_CHECK,
            SET_LIQUIDATION_INCENTIVE_OWNER_CHECK,
            SET_LIQUIDATION_INCENTIVE_VALIDATION,
            SET_MAX_ASSETS_OWNER_CHECK,
            SET_PENDING_ADMIN_OWNER_CHECK,
            SET_PENDING_IMPLEMENTATION_OWNER_CHECK,
            SET_PRICE_ORACLE_OWNER_CHECK,
            SUPPORT_MARKET_EXISTS,
            SUPPORT_MARKET_OWNER_CHECK,
            SET_PAUSE_GUARDIAN_OWNER_CHECK
      }

      /**
         * @dev `error` corresponds to enum Error; `info` corresponds to enum FailureInfo, and `detail` is an
arbitrary
         * contract-specific code that enables us to report opaque error codes from upgradeable contracts.
         **/
      event Failure(uint error, uint info, uint detail);

      /**
         * @dev use this when reporting a known error from the money market or a non-upgradeable collaborator
         */
      function fail(Error err, FailureInfo info) internal returns (uint) {
            emit Failure(uint(err), uint(info), 0);

            return uint(err);
      }

      /**
         * @dev use this when reporting an opaque error from an upgradeable collaborator contract
         */
      function failOpaque(Error err, FailureInfo info, uint opaqueError) internal returns (uint) {
            emit Failure(uint(err), uint(info), opaqueError);

            return uint(err);
      }
}

contract TokenErrorReporter {
      enum Error {
            NO_ERROR,
            UNAUTHORIZED,
            BAD_INPUT,
            ChannelsTROLLER_REJECTION,
            ChannelsTROLLER_CALCULATION_ERROR,
            INTEREST_RATE_MODEL_ERROR,
            INVALID_ACCOUNT_PAIR,
            INVALID_CLOSE_AMOUNT_REQUESTED,
            INVALID_COLLATERAL_FACTOR,
            MATH_ERROR,
            MARKET_NOT_FRESH,
            MARKET_NOT_LISTED,
            TOKEN_INSUFFICIENT_ALLOWANCE,
            TOKEN_INSUFFICIENT_BALANCE,
            TOKEN_INSUFFICIENT_CASH,
            TOKEN_TRANSFER_IN_FAILED,
            TOKEN_TRANSFER_OUT_FAILED
      }

      /*
        * Note: FailureInfo (but not Error) is kept in alphabetical order
        *           This is because FailureInfo grows significantly faster, and
        *           the order of Error has some meaning, while the order of FailureInfo
        *           is entirely arbitrary.
        */
      enum FailureInfo {
            ACCEPT_ADMIN_PENDING_ADMIN_CHECK,
            ACCRUE_INTEREST_ACCUMULATED_INTEREST_CALCULATION_FAILED,
            ACCRUE_INTEREST_BORROW_RATE_CALCULATION_FAILED,
            ACCRUE_INTEREST_NEW_BORROW_INDEX_CALCULATION_FAILED,
            ACCRUE_INTEREST_NEW_TOTAL_BORROWS_CALCULATION_FAILED,
            ACCRUE_INTEREST_NEW_TOTAL_RESERVES_CALCULATION_FAILED,
            ACCRUE_INTEREST_SIMPLE_INTEREST_FACTOR_CALCULATION_FAILED,
            BORROW_ACCUMULATED_BALANCE_CALCULATION_FAILED,
            BORROW_ACCRUE_INTEREST_FAILED,
            BORROW_CASH_NOT_AVAILABLE,
            BORROW_FRESHNESS_CHECK,
            BORROW_NEW_TOTAL_BALANCE_CALCULATION_FAILED,
            BORROW_NEW_ACCOUNT_BORROW_BALANCE_CALCULATION_FAILED,
            BORROW_MARKET_NOT_LISTED,
            BORROW_ChannelsTROLLER_REJECTION,
            LIQUIDATE_ACCRUE_BORROW_INTEREST_FAILED,
            LIQUIDATE_ACCRUE_COLLATERAL_INTEREST_FAILED,
        LIQUIDATE_COLLATERAL_FRESHNESS_CHECK,
        LIQUIDATE_ChannelsTROLLER_REJECTION,
        LIQUIDATE_ChannelsTROLLER_CALCULATE_AMOUNT_SEIZE_FAILED,
        LIQUIDATE_CLOSE_AMOUNT_IS_UINT_MAX,
        LIQUIDATE_CLOSE_AMOUNT_IS_ZERO,
        LIQUIDATE_FRESHNESS_CHECK,
        LIQUIDATE_LIQUIDATOR_IS_BORROWER,
        LIQUIDATE_REPAY_BORROW_FRESH_FAILED,
        LIQUIDATE_SEIZE_BALANCE_INCREMENT_FAILED,
        LIQUIDATE_SEIZE_BALANCE_DECREMENT_FAILED,
        LIQUIDATE_SEIZE_ChannelsTROLLER_REJECTION,
        LIQUIDATE_SEIZE_LIQUIDATOR_IS_BORROWER,
        LIQUIDATE_SEIZE_TOO_MUCH,
        MINT_ACCRUE_INTEREST_FAILED,
        MINT_ChannelsTROLLER_REJECTION,
        MINT_EXCHANGE_CALCULATION_FAILED,
        MINT_EXCHANGE_RATE_READ_FAILED,
        MINT_FRESHNESS_CHECK,
        MINT_NEW_ACCOUNT_BALANCE_CALCULATION_FAILED,
        MINT_NEW_TOTAL_SUPPLY_CALCULATION_FAILED,
        MINT_TRANSFER_IN_FAILED,
        MINT_TRANSFER_IN_NOT_POSSIBLE,
        REDEEM_ACCRUE_INTEREST_FAILED,
        REDEEM_ChannelsTROLLER_REJECTION,
        REDEEM_EXCHANGE_TOKENS_CALCULATION_FAILED,
        REDEEM_EXCHANGE_AMOUNT_CALCULATION_FAILED,
        REDEEM_EXCHANGE_RATE_READ_FAILED,
        REDEEM_FRESHNESS_CHECK,
        REDEEM_NEW_ACCOUNT_BALANCE_CALCULATION_FAILED,
        REDEEM_NEW_TOTAL_SUPPLY_CALCULATION_FAILED,
        REDEEM_TRANSFER_OUT_NOT_POSSIBLE,
        REDUCE_RESERVES_ACCRUE_INTEREST_FAILED,
        REDUCE_RESERVES_ADMIN_CHECK,
        REDUCE_RESERVES_CASH_NOT_AVAILABLE,
        REDUCE_RESERVES_FRESH_CHECK,
        REDUCE_RESERVES_VALIDATION,
        REPAY_BEHALF_ACCRUE_INTEREST_FAILED,
        REPAY_BORROW_ACCRUE_INTEREST_FAILED,
        REPAY_BORROW_ACCUMULATED_BALANCE_CALCULATION_FAILED,
        REPAY_BORROW_ChannelsTROLLER_REJECTION,
        REPAY_BORROW_FRESHNESS_CHECK,
        REPAY_BORROW_NEW_ACCOUNT_BORROW_BALANCE_CALCULATION_FAILED,
        REPAY_BORROW_NEW_TOTAL_BALANCE_CALCULATION_FAILED,
        REPAY_BORROW_TRANSFER_IN_NOT_POSSIBLE,
        SET_COLLATERAL_FACTOR_OWNER_CHECK,
        SET_COLLATERAL_FACTOR_VALIDATION,
        SET_ChannelsTROLLER_OWNER_CHECK,
        SET_INTEREST_RATE_MODEL_ACCRUE_INTEREST_FAILED,
        SET_INTEREST_RATE_MODEL_FRESH_CHECK,
        SET_INTEREST_RATE_MODEL_OWNER_CHECK,
        SET_MAX_ASSETS_OWNER_CHECK,
        SET_ORACLE_MARKET_NOT_LISTED,
        SET_PENDING_ADMIN_OWNER_CHECK,
        SET_RESERVE_FACTOR_ACCRUE_INTEREST_FAILED,
        SET_RESERVE_FACTOR_ADMIN_CHECK,
        SET_RESERVE_FACTOR_FRESH_CHECK,
        SET_RESERVE_FACTOR_BOUNDS_CHECK,
        TRANSFER_ChannelsTROLLER_REJECTION,
        TRANSFER_NOT_ALLOWED,
        TRANSFER_NOT_ENOUGH,
        TRANSFER_TOO_MUCH,
        ADD_RESERVES_ACCRUE_INTEREST_FAILED,
        ADD_RESERVES_FRESH_CHECK,
        ADD_RESERVES_TRANSFER_IN_NOT_POSSIBLE
    }

    /**
      * @dev `error` corresponds to enum Error; `info` corresponds to enum FailureInfo, and `detail` is an
arbitrary
      * contract-specific code that enables us to report opaque error codes from upgradeable contracts.
      **/
    event Failure(uint error, uint info, uint detail);

    /**
      * @dev use this when reporting a known error from the money market or a non-upgradeable collaborator
      */
    function fail(Error err, FailureInfo info) internal returns (uint) {
        emit Failure(uint(err), uint(info), 0);

        return uint(err);
    }

    /**
      * @dev use this when reporting an opaque error from an upgradeable collaborator contract
      */
    function failOpaque(Error err, FailureInfo info, uint opaqueError) internal returns (uint) {
        emit Failure(uint(err), uint(info), opaqueError);
        return uint(err);
    }
}
```

Exponential.sol

```
pragma solidity ^0.5.16;

import "./CarefulMath.sol";

/**
 * @title Exponential module for storing fixed-precision decimals
 * @author Channels
 * @notice Exp is a struct which stores decimals with a fixed precision of 18 decimal places.
 *         Thus, if we wanted to store the 5.1, mantissa would store 5.1e18. That is:
 *         `Exp({mantissa: 5100000000000000000})`.
 */
contract Exponential is CarefulMath {
    uint constant expScale = 1e18;
    uint constant doubleScale = 1e36;
    uint constant halfExpScale = expScale/2;
    uint constant mantissaOne = expScale;

    struct Exp {
        uint mantissa;
    }

    struct Double {
        uint mantissa;
    }

    /**
     * @dev Creates an exponential from numerator and denominator values.
     *      Note: Returns an error if (`num` * 10e18) > MAX_INT,
     *            or if `denom` is zero.
     */
    function getExp(uint num, uint denom) pure internal returns (MathError, Exp memory) {
        (MathError err0, uint scaledNumerator) = mulUInt(num, expScale);
        if (err0 != MathError.NO_ERROR) {
            return (err0, Exp({mantissa: 0}));
        }

        (MathError err1, uint rational) = divUInt(scaledNumerator, denom);
        if (err1 != MathError.NO_ERROR) {
            return (err1, Exp({mantissa: 0}));
        }

        return (MathError.NO_ERROR, Exp({mantissa: rational}));
    }

    /**
     * @dev Adds two exponentials, returning a new exponential.
     */
    function addExp(Exp memory a, Exp memory b) pure internal returns (MathError, Exp memory) {
        (MathError error, uint result) = addUInt(a.mantissa, b.mantissa);

        return (error, Exp({mantissa: result}));
    }

    /**
     * @dev Subtracts two exponentials, returning a new exponential.
     */
    function subExp(Exp memory a, Exp memory b) pure internal returns (MathError, Exp memory) {
        (MathError error, uint result) = subUInt(a.mantissa, b.mantissa);

        return (error, Exp({mantissa: result}));
    }

    /**
     * @dev Multiply an Exp by a scalar, returning a new Exp.
     */
    function mulScalar(Exp memory a, uint scalar) pure internal returns (MathError, Exp memory) {
        (MathError err0, uint scaledMantissa) = mulUInt(a.mantissa, scalar);
        if (err0 != MathError.NO_ERROR) {
            return (err0, Exp({mantissa: 0}));
        }

        return (MathError.NO_ERROR, Exp({mantissa: scaledMantissa}));
    }

    /**
     * @dev Multiply an Exp by a scalar, then truncate to return an unsigned integer.
     */
    function mulScalarTruncate(Exp memory a, uint scalar) pure internal returns (MathError, uint) {
        (MathError err, Exp memory product) = mulScalar(a, scalar);
        if (err != MathError.NO_ERROR) {
            return (err, 0);
        }

        return (MathError.NO_ERROR, truncate(product));
    }

    /**
     * @dev Multiply an Exp by a scalar, truncate, then add an to an unsigned integer, returning an unsigned
integer.
     */
    function mulScalarTruncateAddUInt(Exp memory a, uint scalar, uint addend) pure internal returns
(MathError, uint) {
        (MathError err, Exp memory product) = mulScalar(a, scalar);
        if (err != MathError.NO_ERROR) {
            return (err, 0);
        }

        return addUInt(truncate(product), addend);
    }

    /**
     * @dev Divide an Exp by a scalar, returning a new Exp.
     */
    function divScalar(Exp memory a, uint scalar) pure internal returns (MathError, Exp memory) {
        (MathError err0, uint descaledMantissa) = divUInt(a.mantissa, scalar);
        if (err0 != MathError.NO_ERROR) {
            return (err0, Exp({mantissa: 0}));
        }

        return (MathError.NO_ERROR, Exp({mantissa: descaledMantissa}));
    }

    /**
     * @dev Divide a scalar by an Exp, returning a new Exp.
     */
    function divScalarByExp(uint scalar, Exp memory divisor) pure internal returns (MathError, Exp memory) {
        /*
          We are doing this as:
          getExp(mulUInt(expScale, scalar), divisor.mantissa)

          How it works:
          Exp = a / b;
          Scalar = s;
          `s / (a / b)` = `b * s / a` and since for an Exp `a = mantissa, b = expScale`
        */
        (MathError err0, uint numerator) = mulUInt(expScale, scalar);
        if (err0 != MathError.NO_ERROR) {
            return (err0, Exp({mantissa: 0}));
        }
        return getExp(numerator, divisor.mantissa);
    }

    /**
     * @dev Divide a scalar by an Exp, then truncate to return an unsigned integer.
     */
    function divScalarByExpTruncate(uint scalar, Exp memory divisor) pure internal returns (MathError, uint) {
        (MathError err, Exp memory fraction) = divScalarByExp(scalar, divisor);
        if (err != MathError.NO_ERROR) {
            return (err, 0);
        }

        return (MathError.NO_ERROR, truncate(fraction));
    }

    /**
     * @dev Multiplies two exponentials, returning a new exponential.
     */
    function mulExp(Exp memory a, Exp memory b) pure internal returns (MathError, Exp memory) {

        (MathError err0, uint doubleScaledProduct) = mulUInt(a.mantissa, b.mantissa);
        if (err0 != MathError.NO_ERROR) {
            return (err0, Exp({mantissa: 0}));
        }

        // We add half the scale before dividing so that we get rounding instead of truncation.
        //  See "Listing 6" and text above it at https://accu.org/index.php/journals/1717
        // Without this change, a result like 6.6...e-19 will be truncated to 0 instead of being rounded to 1e-18.
        (MathError err1, uint doubleScaledProductWithHalfScale) = addUInt(halfExpScale,
doubleScaledProduct);
        if (err1 != MathError.NO_ERROR) {
            return (err1, Exp({mantissa: 0}));
        }

        (MathError err2, uint product) = divUInt(doubleScaledProductWithHalfScale, expScale);
        // The only error `div` can return is MathError.DIVISION_BY_ZERO but we control `expScale` and it is
not zero.
        assert(err2 == MathError.NO_ERROR);
        return (MathError.NO_ERROR, Exp({mantissa: product}));
    }

    /**
     * @dev Multiplies two exponentials given their mantissas, returning a new exponential.
     */
    function mulExp(uint a, uint b) pure internal returns (MathError, Exp memory) {
        return mulExp(Exp({mantissa: a}), Exp({mantissa: b}));
    }

    /**
     * @dev Multiplies three exponentials, returning a new exponential.
     */
    function mulExp3(Exp memory a, Exp memory b, Exp memory c) pure internal returns (MathError, Exp
memory) {
        (MathError err, Exp memory ab) = mulExp(a, b);
        if (err != MathError.NO_ERROR) {
            return (err, ab);
        }
        return mulExp(ab, c);
    }

    /**
     * @dev Divides two exponentials, returning a new exponential.
     *     (a/scale) / (b/scale) = (a/scale) * (scale/b) = a/b,
     *  which we can scale as an Exp by calling getExp(a.mantissa, b.mantissa)
     */
    function divExp(Exp memory a, Exp memory b) pure internal returns (MathError, Exp memory) {
        return getExp(a.mantissa, b.mantissa);
    }

    /**
     * @dev Truncates the given exp to a whole number value.
     *      For example, truncate(Exp{mantissa: 15 * expScale}) = 15
     */
    function truncate(Exp memory exp) pure internal returns (uint) {
        // Note: We are not using careful math here as we're performing a division that cannot fail
        return exp.mantissa / expScale;
    }

    /**
     * @dev Checks if first Exp is less than second Exp.
     */
    function lessThanExp(Exp memory left, Exp memory right) pure internal returns (bool) {
        return left.mantissa < right.mantissa;
    }

    /**
     * @dev Checks if left Exp <= right Exp.
     */
    function lessThanOrEqualExp(Exp memory left, Exp memory right) pure internal returns (bool) {
        return left.mantissa <= right.mantissa;
    }

    /**
     * @dev Checks if left Exp > right Exp.
     */
    function greaterThanExp(Exp memory left, Exp memory right) pure internal returns (bool) {
        return left.mantissa > right.mantissa;
    }

    /**
     * @dev returns true if Exp is exactly zero
     */
    function isZeroExp(Exp memory value) pure internal returns (bool) {
        return value.mantissa == 0;
    }

    function safe224(uint n, string memory errorMessage) pure internal returns (uint224) {
        require(n < 2**224, errorMessage);
        return uint224(n);
    }

    function safe32(uint n, string memory errorMessage) pure internal returns (uint32) {
        require(n < 2**32, errorMessage);
        return uint32(n);
    }

    function add_(Exp memory a, Exp memory b) pure internal returns (Exp memory) {
        return Exp({mantissa: add_(a.mantissa, b.mantissa)});
    }

    function add_(Double memory a, Double memory b) pure internal returns (Double memory) {
        return Double({mantissa: add_(a.mantissa, b.mantissa)});
    }
    function add_(uint a, uint b) pure internal returns (uint) {
        return add_(a, b, "addition overflow");
    }

    function add_(uint a, uint b, string memory errorMessage) pure internal returns (uint) {
        uint c = a + b;
        require(c >= a, errorMessage);
        return c;
    }

    function sub_(Exp memory a, Exp memory b) pure internal returns (Exp memory) {
        return Exp({mantissa: sub_(a.mantissa, b.mantissa)});
    }

    function sub_(Double memory a, Double memory b) pure internal returns (Double memory) {
        return Double({mantissa: sub_(a.mantissa, b.mantissa)});
    }

    function sub_(uint a, uint b) pure internal returns (uint) {
        return sub_(a, b, "subtraction underflow");
    }

    function sub_(uint a, uint b, string memory errorMessage) pure internal returns (uint) {
        require(b <= a, errorMessage);
        return a - b;
    }

    function mul_(Exp memory a, Exp memory b) pure internal returns (Exp memory) {
        return Exp({mantissa: mul_(a.mantissa, b.mantissa) / expScale});
    }

    function mul_(Exp memory a, uint b) pure internal returns (Exp memory) {
        return Exp({mantissa: mul_(a.mantissa, b)});
    }

    function mul_(uint a, Exp memory b) pure internal returns (uint) {
        return mul_(a, b.mantissa) / expScale;
    }

    function mul_(Double memory a, Double memory b) pure internal returns (Double memory) {
        return Double({mantissa: mul_(a.mantissa, b.mantissa) / doubleScale});
    }

    function mul_(Double memory a, uint b) pure internal returns (Double memory) {
        return Double({mantissa: mul_(a.mantissa, b)});
    }

    function mul_(uint a, Double memory b) pure internal returns (uint) {
        return mul_(a, b.mantissa) / doubleScale;
    }

    function mul_(uint a, uint b) pure internal returns (uint) {
        return mul_(a, b, "multiplication overflow");
    }

    function mul_(uint a, uint b, string memory errorMessage) pure internal returns (uint) {
        if (a == 0 || b == 0) {
            return 0;
        }
        uint c = a * b;
        require(c / a == b, errorMessage);
        return c;
    }

    function div_(Exp memory a, Exp memory b) pure internal returns (Exp memory) {
        return Exp({mantissa: div_(mul_(a.mantissa, expScale), b.mantissa)});
    }

    function div_(Exp memory a, uint b) pure internal returns (Exp memory) {
        return Exp({mantissa: div_(a.mantissa, b)});
    }

    function div_(uint a, Exp memory b) pure internal returns (uint) {
        return div_(mul_(a, expScale), b.mantissa);
    }

    function div_(Double memory a, Double memory b) pure internal returns (Double memory) {
        return Double({mantissa: div_(mul_(a.mantissa, doubleScale), b.mantissa)});
    }

    function div_(Double memory a, uint b) pure internal returns (Double memory) {
        return Double({mantissa: div_(a.mantissa, b)});
    }

    function div_(uint a, Double memory b) pure internal returns (uint) {
        return div_(mul_(a, doubleScale), b.mantissa);
    }
    function div_(uint a, uint b) pure internal returns (uint) {
        return div_(a, b, "divide by zero");
    }

    function div_(uint a, uint b, string memory errorMessage) pure internal returns (uint) {
        require(b > 0, errorMessage);
        return a / b;
    }

    function fraction(uint a, uint b) pure internal returns (Double memory) {
        return Double({mantissa: div_(mul_(a, doubleScale), b)});
    }
}
```

InterestRateModel.sol

```
pragma solidity ^0.5.16;

/**
  * @title Channels's InterestRateModel Interface
  * @author Channels
  */
contract InterestRateModel {
    /// @notice Indicator that this is an InterestRateModel contract (for inspection)
    bool public constant isInterestRateModel = true;

    /**
      * @notice Calculates the current borrow interest rate per block
      * @param cash The total amount of cash the market has
      * @param borrows The total amount of borrows the market has outstanding
      * @param reserves The total amnount of reserves the market has
      * @return The borrow rate per block (as a percentage, and scaled by 1e18)
      */
    function getBorrowRate(uint cash, uint borrows, uint reserves) external view returns (uint);

    /**
      * @notice Calculates the current supply interest rate per block
      * @param cash The total amount of cash the market has
      * @param borrows The total amount of borrows the market has outstanding
      * @param reserves The total amnount of reserves the market has
      * @param reserveFactorMantissa The current reserve factor the market has
      * @return The supply rate per block (as a percentage, and scaled by 1e18)
      */
    function getSupplyRate(uint cash, uint borrows, uint reserves, uint reserveFactorMantissa) external view
returns (uint);

}
```

Maximillion.sol

```
pragma solidity ^0.5.16;

import "./CHT.sol";

/**
 * @title Channels's Maximillion Contract
 * @author Channels
 */
contract Maximillion {
    /**
     * @notice The default cHT market to repay in
     */
    CHT public cHT;

    /**
     * @notice Construct a Maximillion to repay max in a CHT market
     */
    constructor(CHT cHT_) public {
        cHT = cHT_;
    }

    /**
     * @notice msg.sender sends HT to repay an account's borrow in the cHT market
     * @dev The provided HT is applied towards the borrow balance, any excess is refunded
     * @param borrower The address of the borrower account to repay on behalf of
     */
    function repayBehalf(address borrower) public payable {
        repayBehalfExplicit(borrower, cHT);
    }

    /**
     * @notice msg.sender sends HT to repay an account's borrow in a cHT market
     * @dev The provided HT is applied towards the borrow balance, any excess is refunded
     * @param borrower The address of the borrower account to repay on behalf of
     * @param cHT_ The address of the cHT contract to repay in
     */
    function repayBehalfExplicit(address borrower, CHT cHT_) public payable {
        uint received = msg.value;
        uint borrows = cHT_.borrowBalanceCurrent(borrower);
        if (received > borrows) {
            cHT_.repayBorrowBehalf.value(borrows)(borrower);
            msg.sender.transfer(received - borrows);
        } else {
            cHT_.repayBorrowBehalf.value(received)(borrower);
        }
    }
}
```

Reservoir.sol

```
pragma solidity ^0.5.16;

/**
 * @title Reservoir Contract
 * @notice Distributes a token to a different contract at a fixed rate.
 * @dev This contract must be poked via the `drip()` function every so often.
 * @author Channels
 */
contract Reservoir {

  /// @notice The block number when the Reservoir started (immutable)
  uint public dripStart;

  /// @notice Tokens per block that to drip to target (immutable)
  uint public dripRate;

  /// @notice Reference to token to drip (immutable)
  EIP20Interface public token;

  /// @notice Target to receive dripped tokens (immutable)
  address public target;

  /// @notice Amount that has already been dripped
  uint public dripped;

  /**
    * @notice Constructs a Reservoir
    * @param dripRate_ Numer of tokens per block to drip
    * @param token_ The token to drip
    * @param target_ The recipient of dripped tokens
    */
  constructor(uint dripRate_, EIP20Interface token_, address target_) public {
    dripStart = block.number;
    dripRate = dripRate_;
    token = token_;
    target = target_;
    dripped = 0;
  }

  /**
    * @notice Drips the maximum amount of tokens to match the drip rate since inception
    * @dev Note: this will only drip up to the amount of tokens available.
    * @return The amount of tokens dripped in this call
    */
  function drip() public returns (uint) {
    // First, read storage into memory
    EIP20Interface token_ = token;
    uint reservoirBalance_ = token_.balanceOf(address(this)); // TODO: Verify this is a static call
    uint dripRate_ = dripRate;
    uint dripStart_ = dripStart;
    uint dripped_ = dripped;
    address target_ = target;
    uint blockNumber_ = block.number;

    // Next, calculate intermediate values
    uint dripTotal_ = mul(dripRate_, blockNumber_ - dripStart_, "dripTotal overflow");
    uint deltaDrip_ = sub(dripTotal_, dripped_, "deltaDrip underflow");
    uint toDrip_ = min(reservoirBalance_, deltaDrip_);
    uint drippedNext_ = add(dripped_, toDrip_, "tautological");

    // Finally, write new `dripped` value and transfer tokens to target
    dripped = drippedNext_;
    token_.transfer(target_, toDrip_);

    return toDrip_;
  }

  /* Internal helper functions for safe math */

  function add(uint a, uint b, string memory errorMessage) internal pure returns (uint) {
    uint c = a + b;
    require(c >= a, errorMessage);
```

```
        return c;
    }

    function sub(uint a, uint b, string memory errorMessage) internal pure returns (uint) {
        require(b <= a, errorMessage);
        uint c = a - b;
        return c;
    }

    function mul(uint a, uint b, string memory errorMessage) internal pure returns (uint) {
        if (a == 0) {
            return 0;
        }
        uint c = a * b;
        require(c / a == b, errorMessage);
        return c;
    }

    function min(uint a, uint b) internal pure returns (uint) {
        if (a <= b) {
            return a;
        } else {
            return b;
        }
    }
}

import "./EIP20Interface.sol";
```

SafeMath.sol

```
pragma solidity ^0.5.16;

// From https://github.com/OpenZeppelin/openzeppelin-contracts/blob/master/contracts/math/Math.sol
// Subject to the MIT license.

/**
 * @dev Wrappers over Solidity's arithmetic operations with added overflow
 * checks.
 *
 * Arithmetic operations in Solidity wrap on overflow. This can easily result
 * in bugs, because programmers usually assume that an overflow raises an
 * error, which is the standard behavior in high level programming languages.
 * `SafeMath` restores this intuition by reverting the transaction when an
 * operation overflows.
 *
 * Using this library instead of the unchecked operations eliminates an entire
 * class of bugs, so it's recommended to use it always.
 */
library SafeMath {
    /**
     * @dev Returns the addition of two unsigned integers, reverting on overflow.
     *
     * Counterpart to Solidity's `+` operator.
     *
     * Requirements:
     * - Addition cannot overflow.
     */
    function add(uint256 a, uint256 b) internal pure returns (uint256) {
        uint256 c = a + b;
        require(c >= a, "SafeMath: addition overflow");

        return c;
    }

    /**
     * @dev Returns the addition of two unsigned integers, reverting with custom message on overflow.
     *
     * Counterpart to Solidity's `+` operator.
     *
     * Requirements:
     * - Addition cannot overflow.
     */
    function add(uint256 a, uint256 b, string memory errorMessage) internal pure returns (uint256) {
        uint256 c = a + b;
        require(c >= a, errorMessage);

        return c;
    }

    /**
     * @dev Returns the subtraction of two unsigned integers, reverting on underflow (when the result is
negative).
     *
     * Counterpart to Solidity's `-` operator.
     *
     * Requirements:
     * - Subtraction cannot underflow.
     */
    function sub(uint256 a, uint256 b) internal pure returns (uint256) {
        return sub(a, b, "SafeMath: subtraction underflow");
    }

    /**
     * @dev Returns the subtraction of two unsigned integers, reverting with custom message on underflow
(when the result is negative).
     *
     * Counterpart to Solidity's `-` operator.
     *
     * Requirements:
     * - Subtraction cannot underflow.
     */
    function sub(uint256 a, uint256 b, string memory errorMessage) internal pure returns (uint256) {
        require(b <= a, errorMessage);
        uint256 c = a - b;

        return c;
    }

    /**
     * @dev Returns the multiplication of two unsigned integers, reverting on overflow.
     *
     * Counterpart to Solidity's `*` operator.
     *
     * Requirements:
     * - Multiplication cannot overflow.
     */
    function mul(uint256 a, uint256 b) internal pure returns (uint256) {
        // Gas optimization: this is cheaper than requiring 'a' not being zero, but the
        // benefit is lost if 'b' is also tested.
        // See: https://github.com/OpenZeppelin/openzeppelin-contracts/pull/522
        if (a == 0) {
            return 0;
        }

        uint256 c = a * b;
        require(c / a == b, "SafeMath: multiplication overflow");

        return c;
    }

    /**
     * @dev Returns the multiplication of two unsigned integers, reverting on overflow.
     *
     * Counterpart to Solidity's `*` operator.
     *
     * Requirements:
     * - Multiplication cannot overflow.
     */
    function mul(uint256 a, uint256 b, string memory errorMessage) internal pure returns (uint256) {
        // Gas optimization: this is cheaper than requiring 'a' not being zero, but the
        // benefit is lost if 'b' is also tested.
        // See: https://github.com/OpenZeppelin/openzeppelin-contracts/pull/522
        if (a == 0) {
            return 0;
        }

        uint256 c = a * b;
        require(c / a == b, errorMessage);

        return c;
    }

    /**
     * @dev Returns the integer division of two unsigned integers.
     * Reverts on division by zero. The result is rounded towards zero.
     *
     * Counterpart to Solidity's `/` operator. Note: this function uses a
     * `revert` opcode (which leaves remaining gas untouched) while Solidity
     * uses an invalid opcode to revert (consuming all remaining gas).
     *
     * Requirements:
     * - The divisor cannot be zero.
     */
    function div(uint256 a, uint256 b) internal pure returns (uint256) {
        return div(a, b, "SafeMath: division by zero");
    }

    /**
     * @dev Returns the integer division of two unsigned integers.
     * Reverts with custom message on division by zero. The result is rounded towards zero.
     *
     * Counterpart to Solidity's `/` operator. Note: this function uses a
```

```
         * `revert` opcode (which leaves remaining gas untouched) while Solidity
         * uses an invalid opcode to revert (consuming all remaining gas).
         *
         * Requirements:
         * - The divisor cannot be zero.
         */
        function div(uint256 a, uint256 b, string memory errorMessage) internal pure returns (uint256) {
                // Solidity only automatically asserts when dividing by 0
                require(b > 0, errorMessage);
                uint256 c = a / b;
                // assert(a == b * c + a % b); // There is no case in which this doesn't hold

                return c;
        }

        /**
         * @dev Returns the remainder of dividing two unsigned integers. (unsigned integer modulo),
         * Reverts when dividing by zero.
         *
         * Counterpart to Solidity's `%` operator. This function uses a `revert`
         * opcode (which leaves remaining gas untouched) while Solidity uses an
         * invalid opcode to revert (consuming all remaining gas).
         *
         * Requirements:
         * - The divisor cannot be zero.
         */
        function mod(uint256 a, uint256 b) internal pure returns (uint256) {
                return mod(a, b, "SafeMath: modulo by zero");
        }

        /**
         * @dev Returns the remainder of dividing two unsigned integers. (unsigned integer modulo),
         * Reverts with custom message when dividing by zero.
         *
         * Counterpart to Solidity's `%` operator. This function uses a `revert`
         * opcode (which leaves remaining gas untouched) while Solidity uses an
         * invalid opcode to revert (consuming all remaining gas).
         *
         * Requirements:
         * - The divisor cannot be zero.
         */
        function mod(uint256 a, uint256 b, string memory errorMessage) internal pure returns (uint256) {
                require(b != 0, errorMessage);
                return a % b;
        }
}
```

Unitroller.sol

```
pragma solidity ^0.5.16;

import "./ErrorReporter.sol";
import "./ComptrollerStorage.sol";
/**
 * @title ComptrollerCore
 * @dev Storage for the comptroller is at this address, while execution is delegated to the
`comptrollerImplementation`.
 * CTokens should reference this contract as their comptroller.
 */
contract Unitroller is UnitrollerAdminStorage, ComptrollerErrorReporter {

        /**
          * @notice Emitted when pendingComptrollerImplementation is changed
          */
        event NewPendingImplementation(address oldPendingImplementation, address newPendingImplementation);

        /**
          * @notice Emitted when pendingComptrollerImplementation is accepted, which means comptroller
implementation is updated
          */
        event NewImplementation(address oldImplementation, address newImplementation);

        /**
          * @notice Emitted when pendingAdmin is changed
          */
        event NewPendingAdmin(address oldPendingAdmin, address newPendingAdmin);

        /**
          * @notice Emitted when pendingAdmin is accepted, which means admin is updated
          */
        event NewAdmin(address oldAdmin, address newAdmin);

        constructor() public {
                // Set admin to caller
                admin = msg.sender;
        }
```

```
    /*** Admin Functions ***/
    function _setPendingImplementation(address newPendingImplementation) public returns (uint) {

        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.SET_PENDING_IMPLEMENTATION_OWNER_CHECK);
        }

        address oldPendingImplementation = pendingComptrollerImplementation;

        pendingComptrollerImplementation = newPendingImplementation;

        emit NewPendingImplementation(oldPendingImplementation, pendingComptrollerImplementation);

        return uint(Error.NO_ERROR);
    }

    /**
    * @notice Accepts new implementation of comptroller. msg.sender must be pendingImplementation
    * @dev Admin function for new implementation to accept it's role as implementation
    * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
    */
    function _acceptImplementation() public returns (uint) {
        // Check caller is pendingImplementation and pendingImplementation ≠ address(0)
        if (msg.sender != pendingComptrollerImplementation || pendingComptrollerImplementation == address(0)) {
            return fail(Error.UNAUTHORIZED, FailureInfo.ACCEPT_PENDING_IMPLEMENTATION_ADDRESS_CHECK);
        }

        // Save current values for inclusion in log
        address oldImplementation = comptrollerImplementation;
        address oldPendingImplementation = pendingComptrollerImplementation;

        comptrollerImplementation = pendingComptrollerImplementation;

        pendingComptrollerImplementation = address(0);

        emit NewImplementation(oldImplementation, comptrollerImplementation);
        emit NewPendingImplementation(oldPendingImplementation, pendingComptrollerImplementation);

        return uint(Error.NO_ERROR);
    }


    /**
      * @notice Begins transfer of admin rights. The newPendingAdmin must call `_acceptAdmin` to finalize the transfer.
      * @dev Admin function to begin change of admin. The newPendingAdmin must call `_acceptAdmin` to finalize the transfer.
      * @param newPendingAdmin New pending admin.
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _setPendingAdmin(address newPendingAdmin) public returns (uint) {
        // Check caller = admin
        if (msg.sender != admin) {
            return fail(Error.UNAUTHORIZED, FailureInfo.SET_PENDING_ADMIN_OWNER_CHECK);
        }

        // Save current value, if any, for inclusion in log
        address oldPendingAdmin = pendingAdmin;

        // Store pendingAdmin with value newPendingAdmin
        pendingAdmin = newPendingAdmin;

        // Emit NewPendingAdmin(oldPendingAdmin, newPendingAdmin)
        emit NewPendingAdmin(oldPendingAdmin, newPendingAdmin);

        return uint(Error.NO_ERROR);
    }

    /**
      * @notice Accepts transfer of admin rights. msg.sender must be pendingAdmin
      * @dev Admin function for pending admin to accept role and update admin
      * @return uint 0=success, otherwise a failure (see ErrorReporter.sol for details)
      */
    function _acceptAdmin() public returns (uint) {
        // Check caller is pendingAdmin and pendingAdmin ≠ address(0)
        if (msg.sender != pendingAdmin || msg.sender == address(0)) {
            return fail(Error.UNAUTHORIZED, FailureInfo.ACCEPT_ADMIN_PENDING_ADMIN_CHECK);
        }

        // Save current values for inclusion in log
        address oldAdmin = admin;
        address oldPendingAdmin = pendingAdmin;
        // Store admin with value pendingAdmin
        admin = pendingAdmin;

        // Clear the pending value
        pendingAdmin = address(0);

        emit NewAdmin(oldAdmin, admin);
        emit NewPendingAdmin(oldPendingAdmin, pendingAdmin);

        return uint(Error.NO_ERROR);
    }

    /**
     * @dev Delegates execution to an implementation contract.
     * It returns to the external caller whatever the implementation returns
     * or forwards reverts.
     */
    function () payable external {
        // delegate all other functions to current implementation
        (bool success, ) = comptrollerImplementation.delegatecall(msg.data);

        assembly {
              let free_mem_ptr := mload(0x40)
              returndatacopy(free_mem_ptr, 0, returndatasize)

              switch success
              case 0 { revert(free_mem_ptr, returndatasize) }
              default { return(free_mem_ptr, returndatasize) }
        }
    }
}
```

WhitePaperInterestRateModel.sol

```
pragma solidity ^0.5.16;

import "./InterestRateModel.sol";
import "./SafeMath.sol";

/**
  * @title Channels's WhitePaperInterestRateModel Contract
  * @author Channels
  * @notice The parameterized model described in section 2.4 of the original Channels Protocol whitepaper
  */
contract WhitePaperInterestRateModel is InterestRateModel {
    using SafeMath for uint;

    event NewInterestParams(uint baseRatePerBlock, uint multiplierPerBlock);

    /**
     * @notice The approximate number of blocks per year that is assumed by the interest rate model
     */
    uint public constant blocksPerYear = 2102400;

    /**
     * @notice The multiplier of utilization rate that gives the slope of the interest rate
     */
    uint public multiplierPerBlock;

    /**
     * @notice The base interest rate which is the y-intercept when utilization rate is 0
     */
    uint public baseRatePerBlock;

    /**
     * @notice Construct an interest rate model
     * @param baseRatePerYear The approximate target base APR, as a mantissa (scaled by 1e18)
     * @param multiplierPerYear The rate of increase in interest rate wrt utilization (scaled by 1e18)
     */
    constructor(uint baseRatePerYear, uint multiplierPerYear) public {
        baseRatePerBlock = baseRatePerYear.div(blocksPerYear);
        multiplierPerBlock = multiplierPerYear.div(blocksPerYear);

        emit NewInterestParams(baseRatePerBlock, multiplierPerBlock);
    }

    /**
     * @notice Calculates the utilization rate of the market: `borrows / (cash + borrows - reserves)`
     * @param cash The amount of cash in the market
     * @param borrows The amount of borrows in the market
     * @param reserves The amount of reserves in the market (currently unused)
     * @return The utilization rate as a mantissa between [0, 1e18]
     */
    function utilizationRate(uint cash, uint borrows, uint reserves) public pure returns (uint) {
        // Utilization rate is 0 when there are no borrows
        if (borrows == 0) {
            return 0;
        }

        return borrows.mul(1e18).div(cash.add(borrows).sub(reserves));
    }

    /**
     * @notice Calculates the current borrow rate per block, with the error code expected by the market
     * @param cash The amount of cash in the market
     * @param borrows The amount of borrows in the market
     * @param reserves The amount of reserves in the market
     * @return The borrow rate percentage per block as a mantissa (scaled by 1e18)
     */
    function getBorrowRate(uint cash, uint borrows, uint reserves) public view returns (uint) {
        uint ur = utilizationRate(cash, borrows, reserves);
        return ur.mul(multiplierPerBlock).div(1e18).add(baseRatePerBlock);
    }

    /**
     * @notice Calculates the current supply rate per block
     * @param cash The amount of cash in the market
     * @param borrows The amount of borrows in the market
     * @param reserves The amount of reserves in the market
     * @param reserveFactorMantissa The current reserve factor for the market
     * @return The supply rate percentage per block as a mantissa (scaled by 1e18)
     */
    function getSupplyRate(uint cash, uint borrows, uint reserves, uint reserveFactorMantissa) public view
returns (uint) {
        uint oneMinusReserveFactor = uint(1e18).sub(reserveFactorMantissa);
        uint borrowRate = getBorrowRate(cash, borrows, reserves);
        uint rateToPool = borrowRate.mul(oneMinusReserveFactor).div(1e18);
        return utilizationRate(cash, borrows, reserves).mul(rateToPool).div(1e18);
    }
}
```

6. 附录 B：安全风险评级标准

智能合约漏洞评级标准

漏洞评级	漏洞评级说明
高危漏洞	能直接造成代币合约或用户资金损失的漏洞，如：能造成代币价值归零的数值溢出漏洞、能造成交易所损失代币的假充值漏洞、能造成合约账户损失 Ether 或代币的重入漏洞等； 能造成代币合约归属权丢失的漏洞，如：关键函数的访问控制缺陷、call 注入导致关键函数访问控制绕过等； 能造成代币合约无法正常工作的漏洞，如：因向恶意地址发送 Ether 导致的拒绝服务漏洞、因 gas 耗尽导致的拒绝服务漏洞。
中危漏洞	需要特定地址才能触发的高风险漏洞，如代币合约拥有者才能触发的数值溢出漏洞等；非关键函数的访问控制缺陷、不能造成直接资金损失的逻辑设计缺陷等。
低危漏洞	难以被触发的漏洞、触发之后危害有限的漏洞，如需要大量 Ether 或代币才能触发的数值溢出漏洞、触发数值溢出后攻击者无法直接获利的漏洞、通过指定高 gas 触发的事务顺序依赖风险等。

7. 附录 C：智能合约安全审计工具简介

6.1 Manticore

Manticore 是一个分析二进制文件和智能合约的符号执行工具，Manticore 包含一个符号 Ethereum 虚拟机（EVM），一个 EVM 反汇编器/汇编器以及一个用于自动编译和分析 Solidity 的方便界面。它还集成了 Ethersplay，用于 EVM 字节码的 Bit of Traits of Bits 可视化反汇编程序，用于可视化分析。 与二进制文件一样，Manticore 提供了一个简单的命令行界面和一个用于分析 EVM 字节码的 Python API。

6.2 Oyente

Oyente 是一个智能合约分析工具，Oyente 可以用来检测智能合约中常见的 bug，比如 reentrancy、事务排序依赖等等。更方便的是，Oyente 的设计是模块化的，所以这让高级用户可以实现并插入他们自己的检测逻辑，以检查他们的合约中自定义的属性。

6.3 securify.sh

Securify 可以验证 Ethereum 智能合约常见的安全问题，例如交易乱序和缺少输入验证，它在全自动化的同时分析程序所有可能的执行路径，此外，Securify 还具有用于指定漏洞的特定语言，这使 Securify 能够随时关注当前的安全性和其他可靠性问题。

6.4 Echidna

Echidna 是一个为了对 EVM 代码进行模糊测试而设计的 Haskell 库。

6.5 MAIAN

MAIAN 是一个用于查找 Ethereum 智能合约漏洞的自动化工具，Maian 处理合

约的字节码，并尝试建立一系列交易以找出并确认错误。

6.6 ethersplay

ethersplay 是一个 EVM 反汇编器，其中包含了相关分析工具。

6.7 ida-evm

ida-evm 是一个针对 Ethereum 虚拟机（EVM）的 IDA 处理器模块。

6.8 Remix-ide

Remix 是一款基于浏览器的编译器和 IDE，可让用户使用 Solidity 语言构建 Ethereum 合约并调试交易。

6.9 知道创宇区块链安全审计人员专用工具包

知道创宇渗透测试人员专用工具包，由知道创宇渗透测试工程师研发，收集和使用，包含专用于测试人员的批量自动测试工具，自主研发的工具、脚本或利用工具等。

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