BitML^x

Cross-chain Smart Contracts for Bitcoin-style Cryptocurrencies

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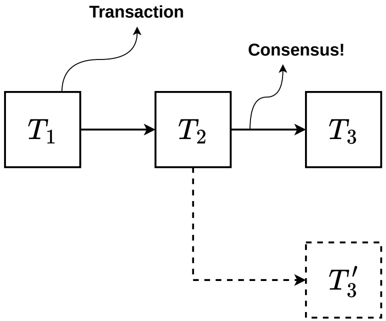
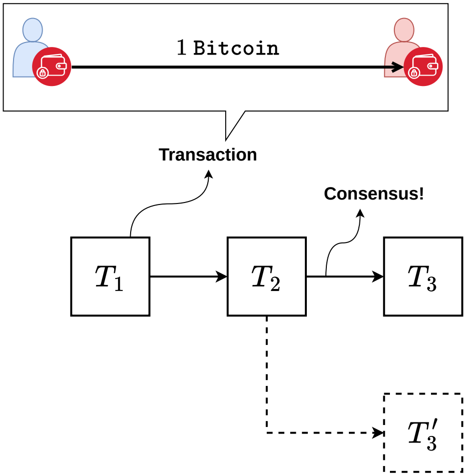
FCS 2023
July 9, 2023

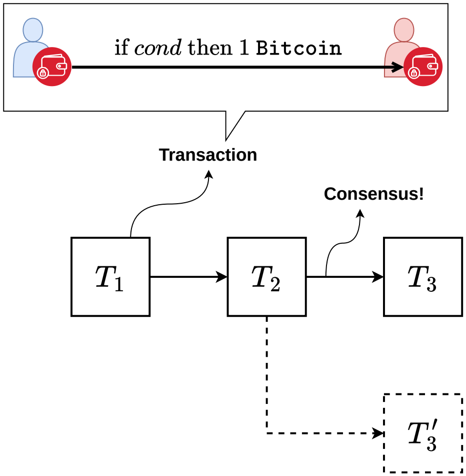
Blockchains



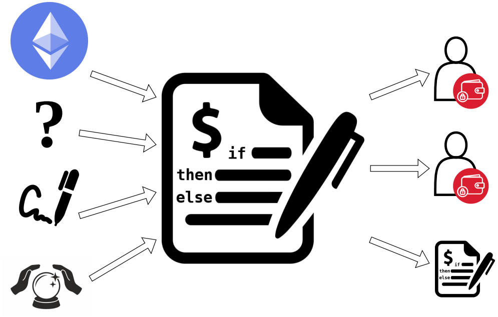
Blockchains



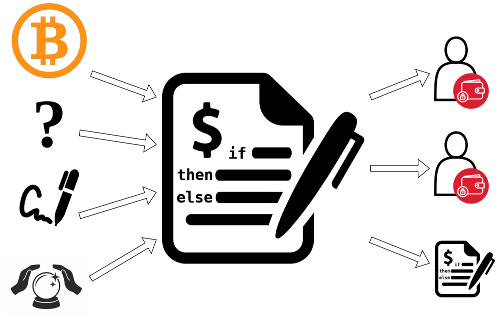
Blockchains



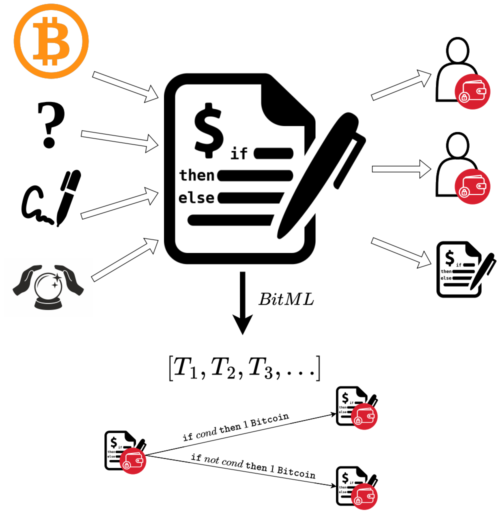
Smart Contracts



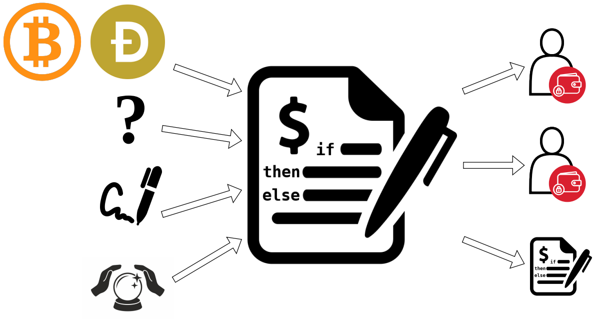
BitML: From Transactions To Smart Contracts



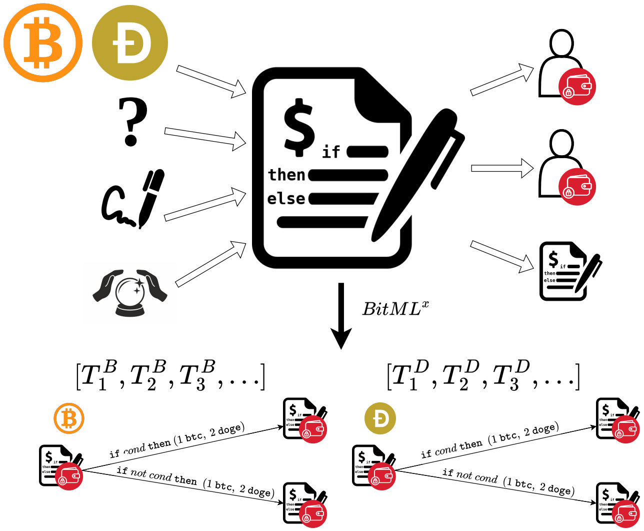
BitML: From Transactions To Smart Contracts



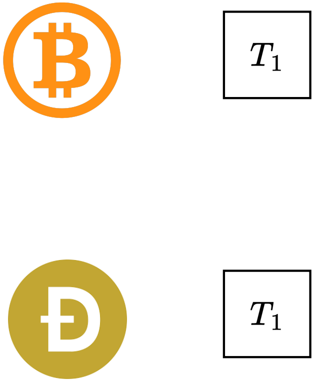
BitML^x: Cross-chain Smart Contracts



BitML^x: Cross-chain Smart Contracts


if
then
else
BitML^x
$[T_1^B, T_2^B, T_3^B, \ldots]$
$[T_1^D, T_2^D, T_3^D, \ldots]$
if cond then (1 btc, 2 doge)
if not cond then (1 btc, 2 doge)
if cond then (1 btc, 2 doge)
if not cond (1 btc, 2 doge)

Cross-chain & Consensus

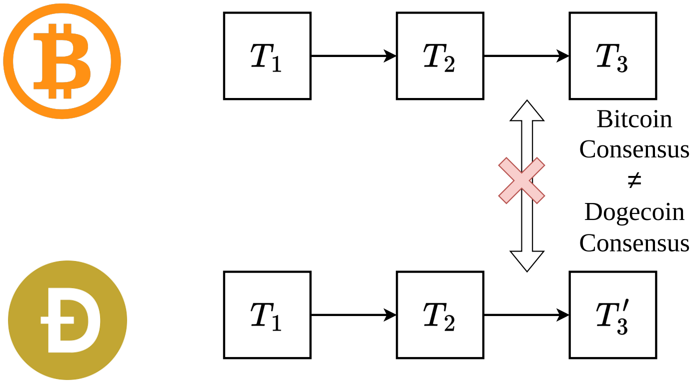


Cross-chain & Consensus

$$\begin{tikzcd} \boxed{T_1} \arrow[r] & \boxed{T_2} \end{tikzcd}$$

$$\begin{tikzcd} \boxed{T_1} \arrow[r] & \boxed{T_2} \end{tikzcd}$$

Cross-chain & Consensus



Presentation Overview

1. BitML & Synchronicity
2. BitML^x
3. Compilation
4. Correctness

BitML syntax

Preconditions:

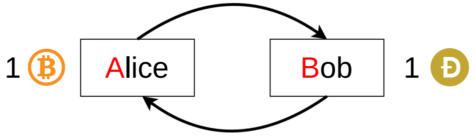
$G ::= A :! v$₿	user deposits
$\mid A :$ `secret` s	secret commitment

Contracts:

$C ::= D_1 + D_2 + \cdots + D_k$	choose any sub-contract
$D ::= A : \ D$	A signs before executing D
$\mid$ `after` $t : D$	wait until t, execute D
$\mid$ `reveal` s `then` C	reveal s before executing C
$\mid$ `split` $\vec{v}$₿ $\to \vec{C}$	split into many contracts
$\mid$ `withdraw` A	A gets the money

(Don't panic: example in next slide.)

Example: Alice Want To Swap Coins



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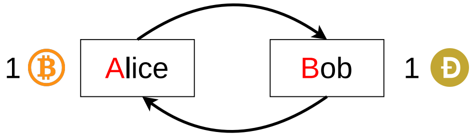
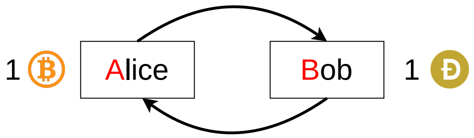


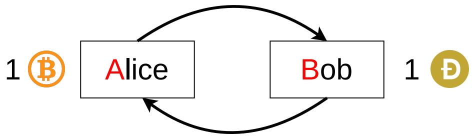
$\{A :! 1฿ \mid B : \texttt{secret } s\}\mathit{Swap}^{฿}$

Example: Alice Want To Swap Coins



$$\underbrace{\{A :! 1\text{₿} \mid B : \texttt{secret } s\}}_{\text{preconditions}} \; \underbrace{\mathit{Swap}^{\text{₿}}}_{\text{contract}}$$

Example: Alice Want To Swap Coins



$$\overbrace{\{\underbrace{A :! 1₿}_{\text{user deposits}} \mid \underbrace{\mid B : \texttt{secret}\ s}_{\text{secret commitments}}\}}^{\text{preconditions}} \overbrace{Swap^{₿}}^{\text{contract}}$$

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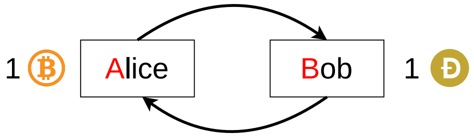

$$\{ \overbrace{\underbrace{A :! 1\text{฿}}_{\text{user deposits}} \quad \mid \quad \underbrace{\mid B : \texttt{secret}\ s}_{\text{secret commitments}}}^{\text{preconditions}} \} \overbrace{Swap^{\text{฿}}}^{\text{contract}} \quad \{B :! 1\text{Ð} \mid B : \texttt{secret}\ s\} Swap^{\text{Ð}}$$

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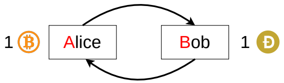
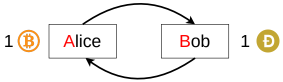


$$\{A :! 1 ฿ \mid B : \texttt{secret } s\} Swap^{฿}$$

$$\{B :! 1 Ɖ \mid B : \texttt{secret } s\} Swap^{Ɖ}$$

Example: Alice Want To Swap Coins

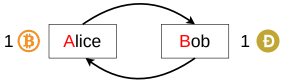


$$\{A :! 1\text{Ƀ} \mid B : \texttt{secret}\ s\}\mathit{Swap}^{\text{Ƀ}}$$

$$\{B :! 1\text{Đ} \mid B : \texttt{secret}\ s\}\mathit{Swap}^{\text{Đ}}$$

$$\mathit{Swap}^{\text{Ƀ}} = \mathit{Exchange}^{\text{Ƀ}} + \mathit{Refund}^{\text{Ƀ}}$$

Example: Alice Want To Swap Coins



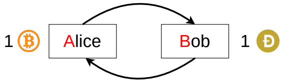
$$\{A :! 1\text{฿} \mid B : \texttt{secret}\ s\}\mathit{Swap}^{\text{฿}}$$

$$\{B :! 1\text{Ɖ} \mid B : \texttt{secret}\ s\}\mathit{Swap}^{\text{Ɖ}}$$

$$\mathit{Swap}^{\text{฿}} = \mathit{Exchange}^{\text{฿}} + \mathit{Refund}^{\text{฿}}$$

$$\mathit{Exchange}^{\text{฿}} = \texttt{reveal}\ s\ .\ \texttt{withdraw}\ B$$

Example: Alice Want To Swap Coins



$$\{A :! 1฿ \mid B : \texttt{secret } s\} Swap^{฿}$$

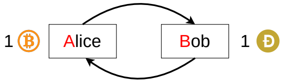
$$\{B :! 1Ɖ \mid B : \texttt{secret } s\} Swap^{Ɖ}$$

$$Swap^{฿} = Exchange^{฿} + Refund^{฿}$$

$$Exchange^{฿} = \texttt{reveal } s \,.\, \texttt{withdraw } B$$

$$Refund^{฿} = \texttt{after } t_0 : \texttt{withdraw } A$$

Example: Alice Want To Swap Coins



$$\{A :! 1\text{฿} \mid B : \texttt{secret } s\}\mathit{Swap}^{\text{฿}}$$

$$\{B :! 1\text{Ð} \mid B : \texttt{secret } s\}\mathit{Swap}^{\text{Ð}}$$

$$\mathit{Swap}^{\text{฿}} = \mathit{Exchange}^{\text{฿}} + \mathit{Refund}^{\text{฿}}$$

$$\mathit{Exchange}^{\text{฿}} = \texttt{reveal } s \,.\, \texttt{withdraw } B$$

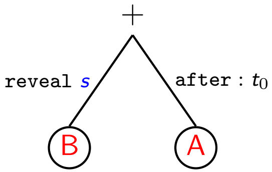
$$\mathit{Refund}^{\text{฿}} = \texttt{after } t_0 : \texttt{withdraw } A$$

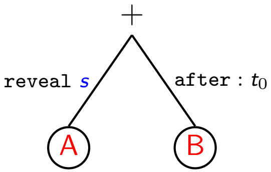
$$\begin{aligned}\mathit{Swap}^{\text{Ð}} = {} & \texttt{reveal } s \,.\, \texttt{withdraw } A \\ & + \texttt{after } t_0 : \texttt{withdraw } B\end{aligned}$$

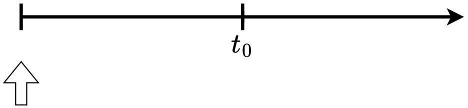
Successful Swap

Alice

Bob





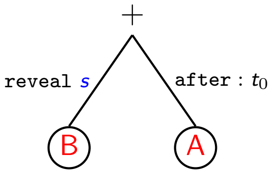


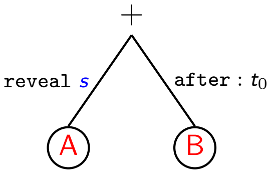
Successful Swap

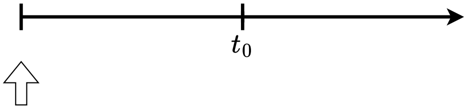
Alice

Bob

- Wanna swap coins?







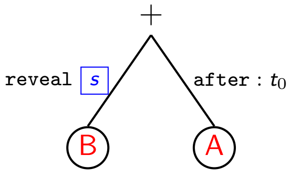
Successful Swap

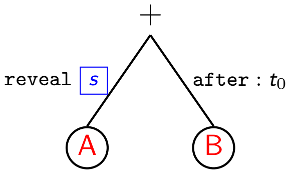
Alice

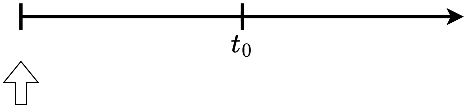
- Wanna swap coins?

Bob

- Sure! Here is $\boxed{s}$.







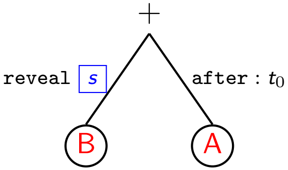
Successful Swap

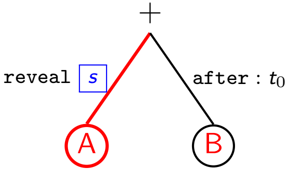
Alice

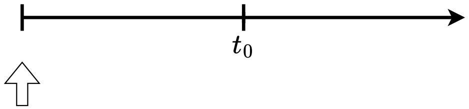
- Wanna swap coins?
- Thanks! I'm taking ₿😄

Bob

- Sure! Here is $\boxed{s}$.







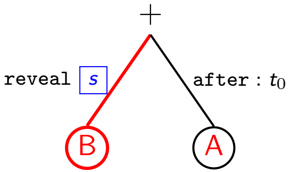
Successful Swap

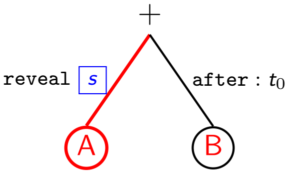
Alice

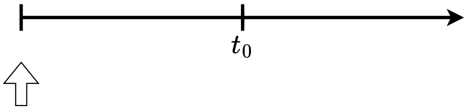
- Wanna swap coins?
- Thanks! I'm taking Đ😄

Bob

- Sure! Here is $\boxed{s}$.
- And I'm taking ฿😄



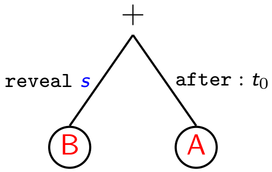


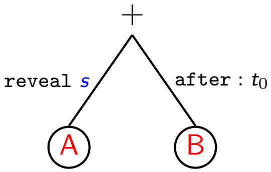


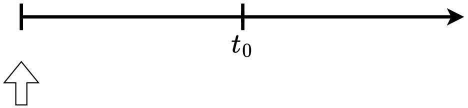
Successful Refund

Alice

Bob





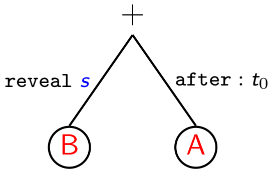


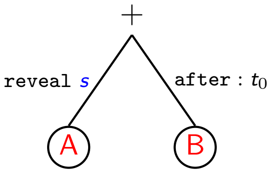
Successful Refund

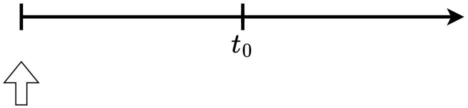
Alice

- Wanna swap coins?

Bob







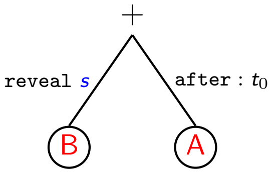
Successful Refund

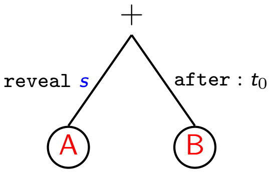
Alice

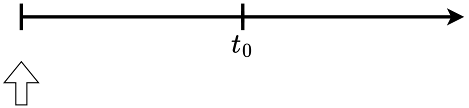
- Wanna swap coins?

Bob

- Not really.







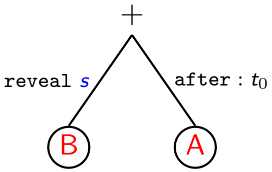
Successful Refund

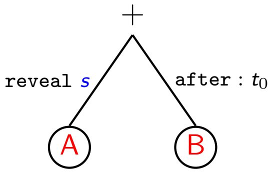
Alice

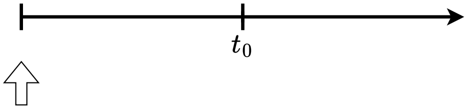
- Wanna swap coins?
- Oh. That's ok. 🥲

Bob

- Not really.







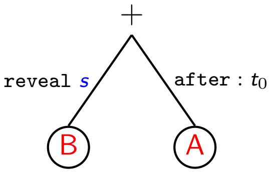
Successful Refund

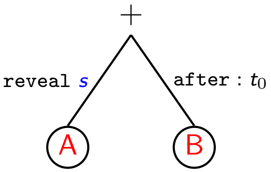
Alice

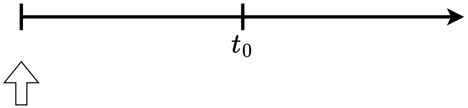
- Wanna swap coins?
- Oh. That's ok. 🥲

Bob

- Not really.
- Yeah, sorry. 😅







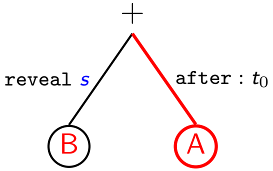
Successful Refund

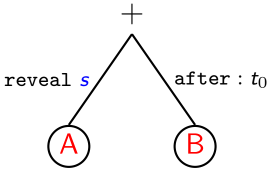
Alice

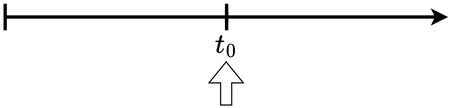
- Wanna swap coins?
- Oh. That's ok. 🥲
- I'll take back my ₿.

Bob

- Not really.
- Yeah, sorry. 😅







Successful Refund

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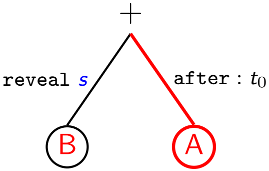
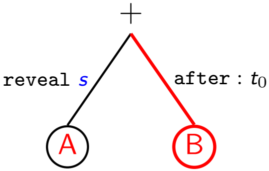
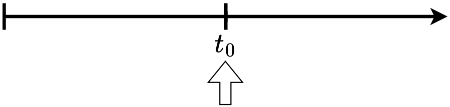


Bob

- Not really.
- Yeah, sorry. 😅
- And I'll take back my Ḋ.

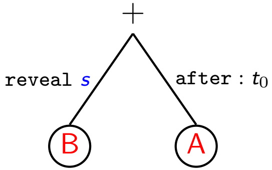


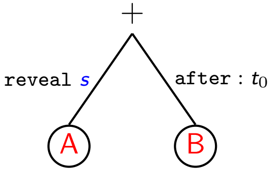


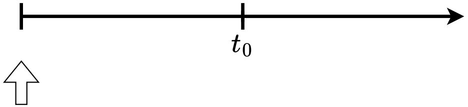
But...

Alice

Bob





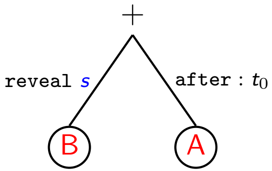


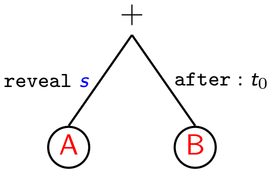
But...

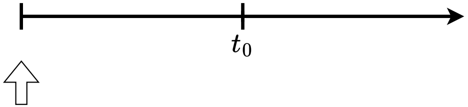
Alice

- Wanna swap coins?

Bob







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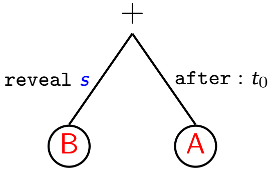
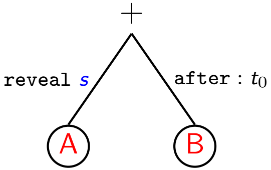
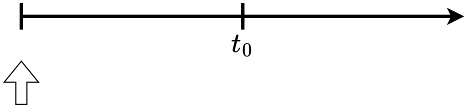






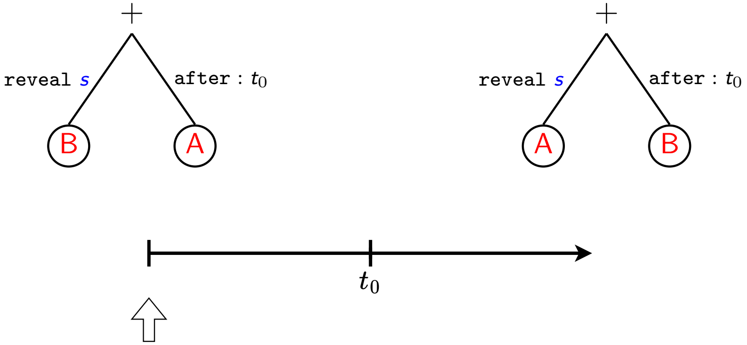
But...

Alice

- Wanna swap coins?
- Oh. That's ok. 🥲

Bob

- Not really.



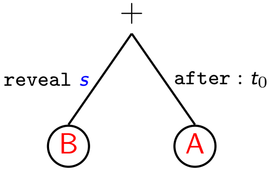
But...

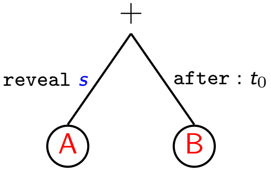
Alice

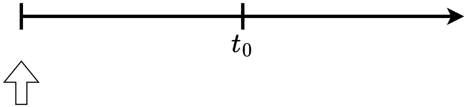
- Wanna swap coins?
- Oh. That's ok. 🥲

Bob

- Not really.
- Yes... totally ok. 😶







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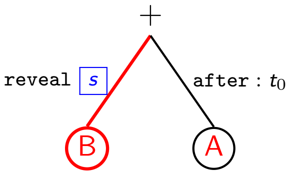
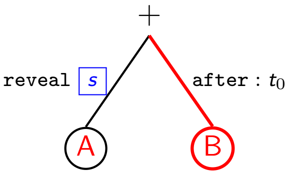
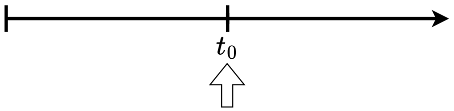






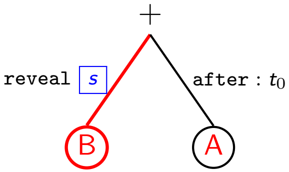
But...

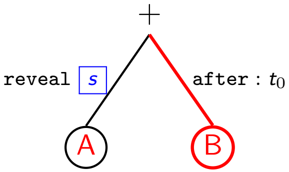
Alice

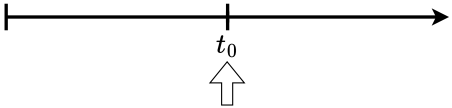
- Wanna swap coins?
- Oh. That's ok. 🥲
- Bob, WTF? 😱

Bob

- Not really.
- Yes... totally ok. 😶
- See ya, looser. 😈







Introducing: BitML^x

Alice should have read the bibliography on sound cryptographic protocol designs.

Introducing: BitML^x

Alice should have ~~read the bibliography on sound cryptographic protocol designs.~~ switched to BitML^x!

$\mathrm{B} = [v_1 \mathbb{B}_1, \ldots, v_k \mathbb{B}_k]$	balance
$G ::= A \;:!\; \mathrm{B}$	user deposit (in all chains)
$\mid A : \texttt{secret}\ s$	secret commitment

$C ::= D \mathrel{+\!\!>} C$	choose D or skip to C
$\mid \texttt{withdraw}\ \vec{\mathrm{B}} \to \vec{A}$	last choice is always `withdraw`
$D ::= A :\ \ D$	
$\mid \texttt{reveal}\ s\ \texttt{then}\ C$	reveal secrets before executing C
$\mid \texttt{split}\ \vec{\mathrm{B}} \to \vec{C}$	split into many contract
$\texttt{withdraw}\ \vec{\mathrm{B}} \to \vec{A}$	distribute the balance among users

Swap In BitML^x

$$\{A\ :!\,(1\text{Ƀ}, 0\text{Đ}) \mid B\ :!\,(0\text{Ƀ}, 1\text{Đ})\}\mathit{Swap}^x$$

Swap In BitML^x

$$\{A \; :! \, (1 Ƀ, 0 Đ) \mid B \; :! \, (0 Ƀ, 1 Đ)\} \mathit{Swap}^x$$
$$\mathit{Swap}^x \; = \mathit{Exchange}^x \; \mathrel{+\!\!>} \; \mathit{Refund}^x$$

Swap In BitML^x

$$\{A :! (1\text{Ƀ}, 0\text{Đ}) \mid B :! (0\text{Ƀ}, 1\text{Đ})\} \mathit{Swap}^x$$
$$\mathit{Swap}^x = \mathit{Exchange}^x \mathrel{+\!\!>} \mathit{Refund}^x$$

$$\begin{aligned}
\mathit{Exchange}^x = \;& \texttt{withdraw}(\\
& \quad (0\text{Ƀ}, 1\text{Đ}) \rightarrow A, \\
& \quad (1\text{Ƀ}, 0\text{Đ}) \rightarrow B \\
&)
\end{aligned}$$

Swap In BitML^x

$$\{A :! (1\text{Ƀ}, 0\text{Đ}) \mid B :! (0\text{Ƀ}, 1\text{Đ})\}\mathit{Swap}^x$$
$$\mathit{Swap}^x = \mathit{Exchange}^x \mathrel{+\!\!>} \mathit{Refund}^x$$

$$\mathit{Exchange}^x = \texttt{withdraw}((0\text{Ƀ}, 1\text{Đ}) \to A, (1\text{Ƀ}, 0\text{Đ}) \to B)$$

$$\mathit{Refund}^x = \texttt{withdraw}((1\text{Ƀ}, 0\text{Đ}) \to A, (0\text{Ƀ}, 1\text{Đ}) \to B)$$

BitML^x Compilation Idea

$$\mathit{Swap}^x \xrightarrow{???} \begin{cases} \vec{T}^x_{\text{₿}} \\ \vec{T}^x_{\text{Ð}} \end{cases}$$

BitML^x Compilation Idea

$$\mathit{Swap}^x \xrightarrow{\text{BitML}^x\text{ compiler}} \begin{cases} \mathit{Swap}^x_{\text{Ƀ}} \xrightarrow{\text{BitML compiler}} \vec{T}^x_{\text{Ƀ}} \\ \mathit{Swap}^x_{\text{Đ}} \xrightarrow{\text{BitML compiler}} \vec{T}^x_{\text{Đ}} \end{cases}$$

BitML^x Compilation Idea

$$\mathit{Swap}^x \xrightarrow{\text{BitML}^x\text{ compiler}} \begin{cases} \mathit{Swap}^x_{\text{₿}} \xrightarrow{\text{BitML compiler}} \vec{T}^x_{\text{₿}} \\ \mathit{Swap}^x_{\text{Ð}} \xrightarrow{\text{BitML compiler}} \vec{T}^x_{\text{Ð}} \end{cases}$$

$$\mathit{Swap}^x_{\text{₿}} \xLeftrightarrow[\text{collaterals}]{\text{step secrets}} \mathit{Swap}^x_{\text{Ð}}$$

BitML^x Compilation Idea

$$\mathit{Swap}^x \xrightarrow{\text{BitML}^x \text{ compiler}} \begin{cases} \mathit{Swap}^x_{₿} \xrightarrow{\text{BitML compiler}} \vec{T}^x_{₿} \\ \mathit{Swap}^x_{Đ} \xrightarrow{\text{BitML compiler}} \vec{T}^x_{Đ} \end{cases}$$

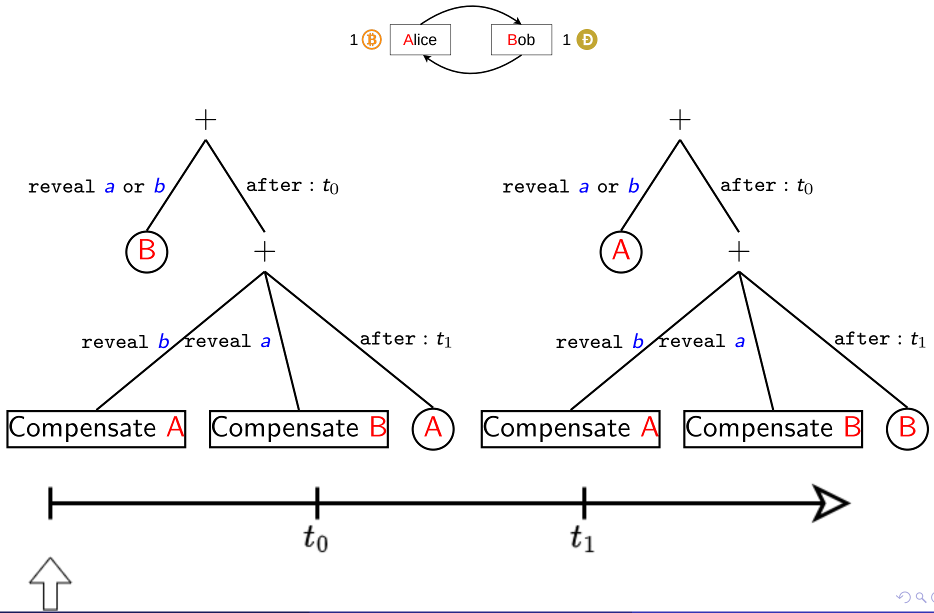
$$\mathit{Swap}^x_{₿} \xLeftrightarrow[\text{collaterals}]{\overbrace{\text{step secrets}}^{\text{prove of execution intent}}} \mathit{Swap}^x_{Đ}$$

BitML^x Compilation Idea

$$Swap^x \xrightarrow{\text{BitML}^x\text{ compiler}} \begin{cases} Swap^x_{Ƀ} \xrightarrow{\text{BitML compiler}} \vec{T}^x_{Ƀ} \\ Swap^x_{Ð} \xrightarrow{\text{BitML compiler}} \vec{T}^x_{Ð} \end{cases}$$

$$Swap^x_{Ƀ} \overset{\overbrace{\text{step secrets}}^{\text{to prove execution intent}}}{\underset{\underbrace{\text{collaterals}}_{\text{to compensate asynchronous behaviours}}}{\Longleftrightarrow}} Swap^x_{Ð}$$

Compilation In Action



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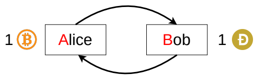

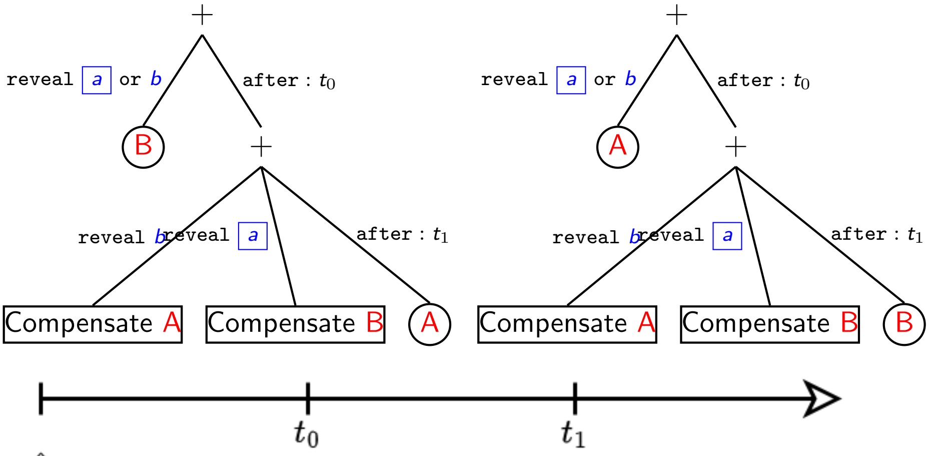

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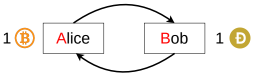

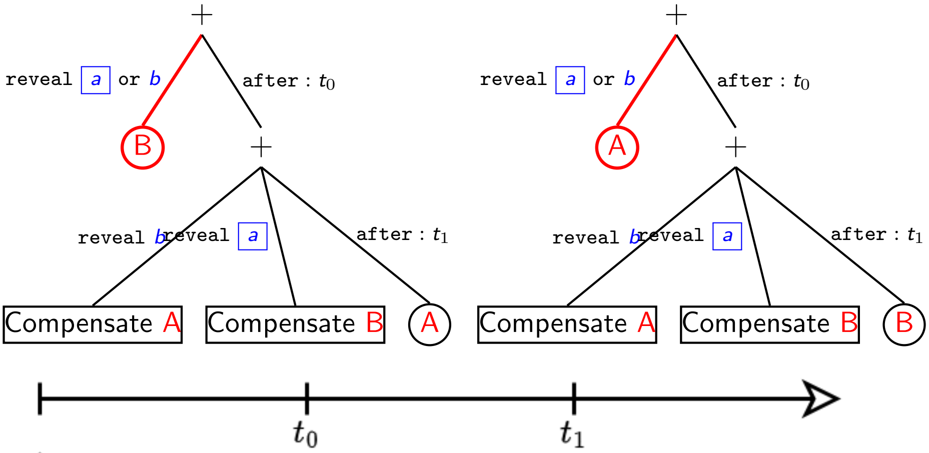

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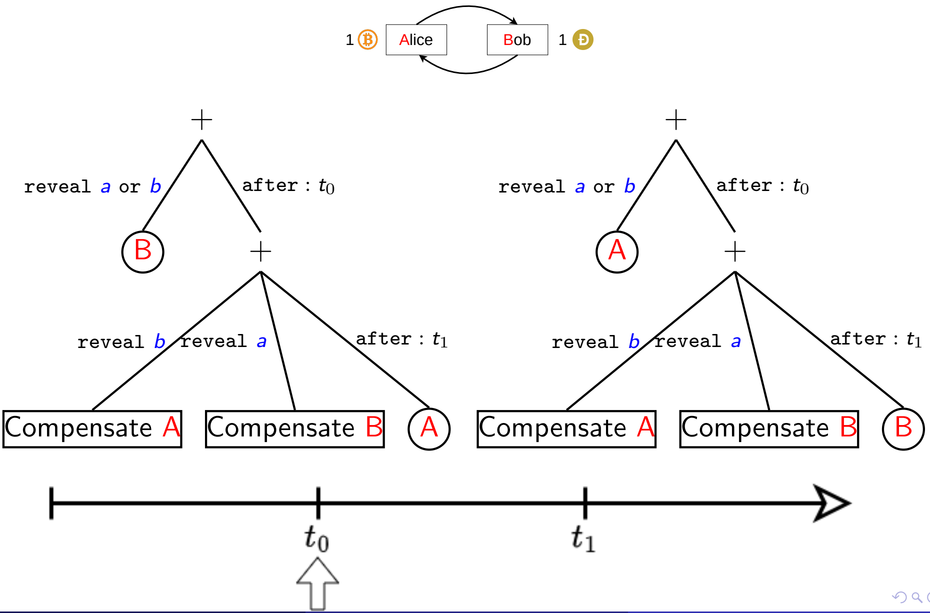

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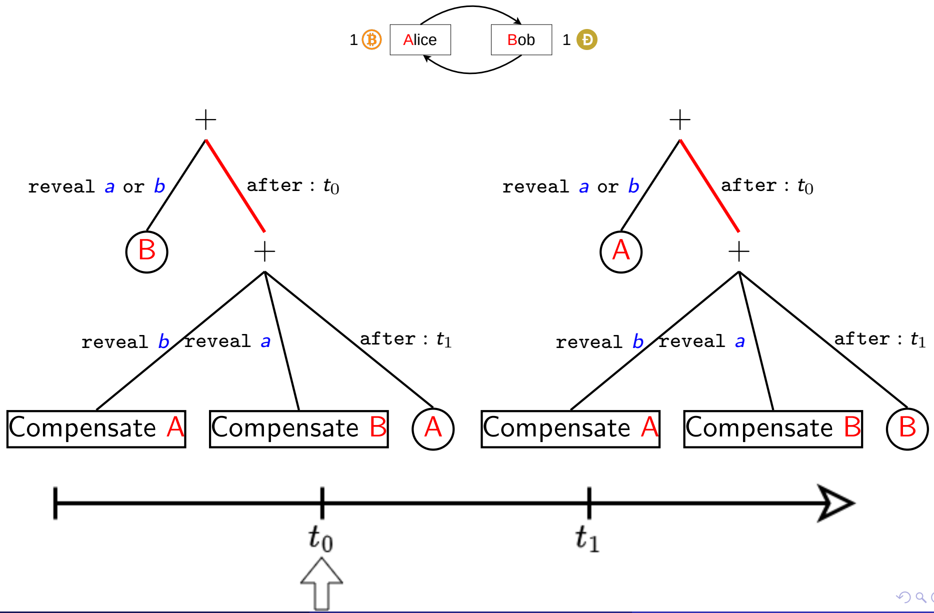

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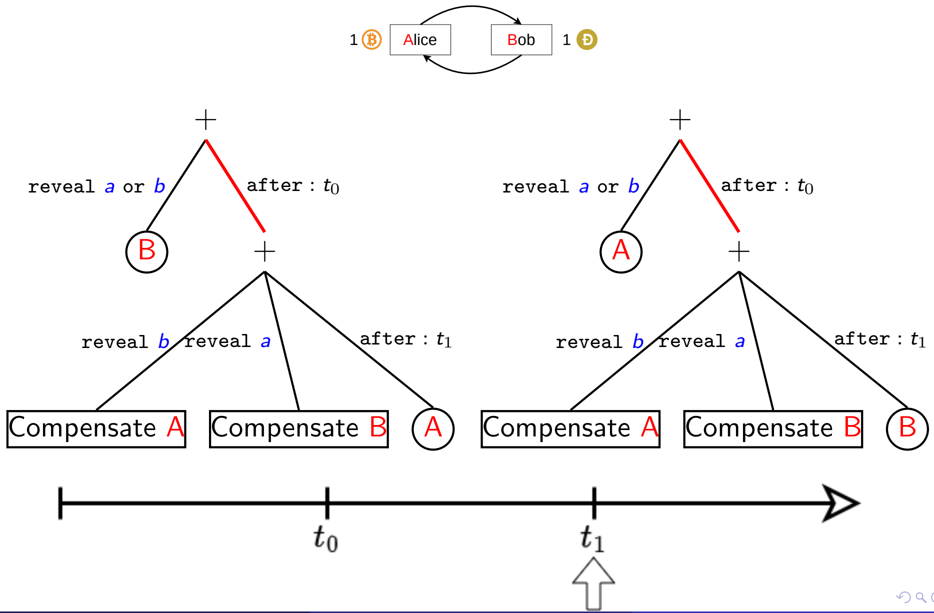

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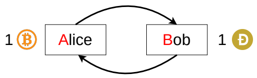

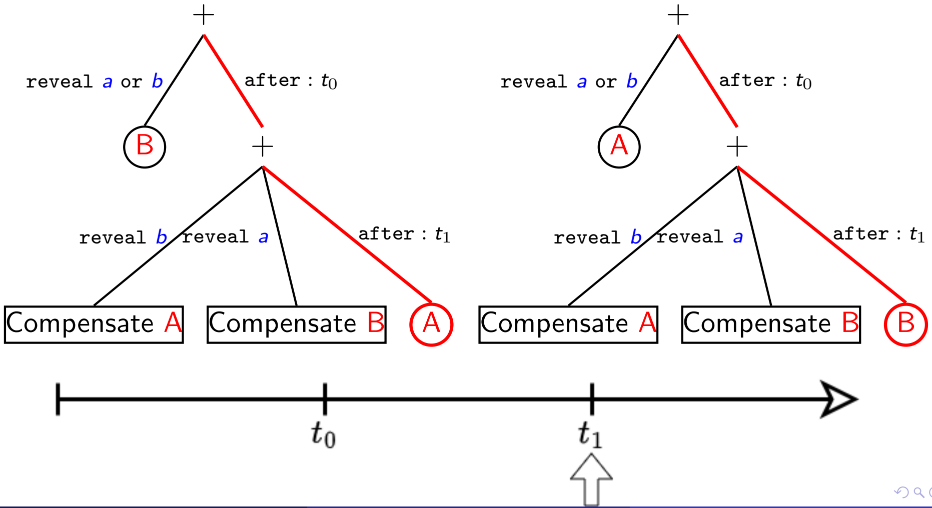

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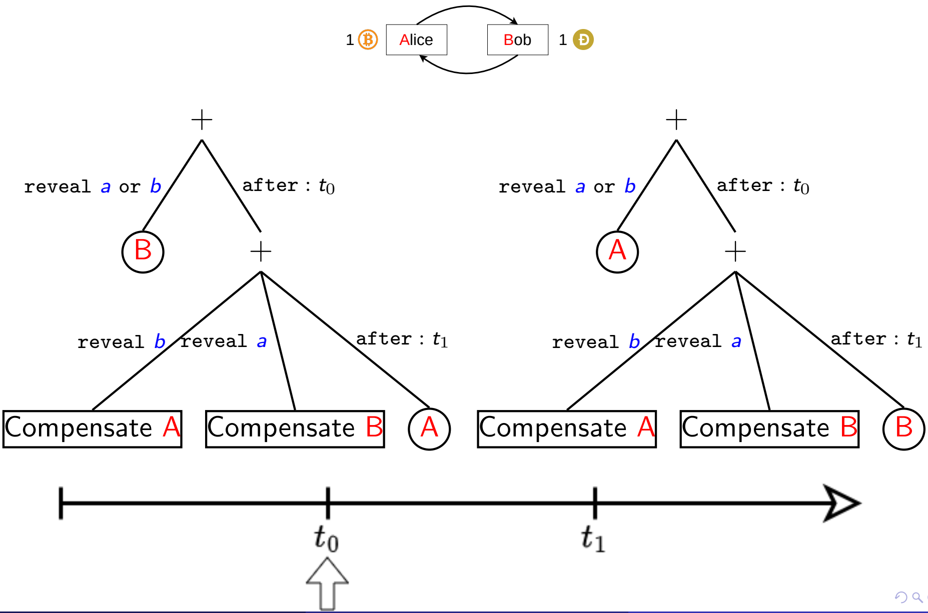

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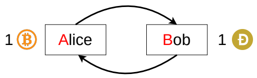

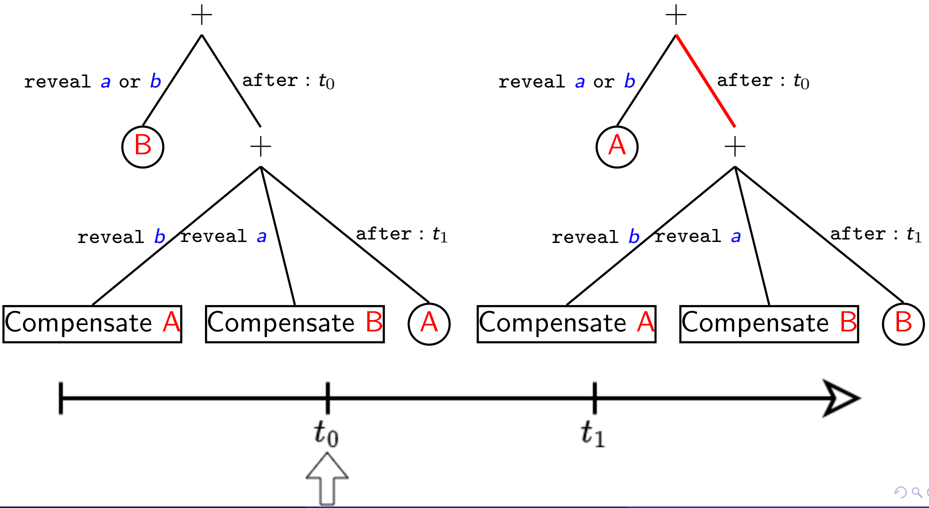

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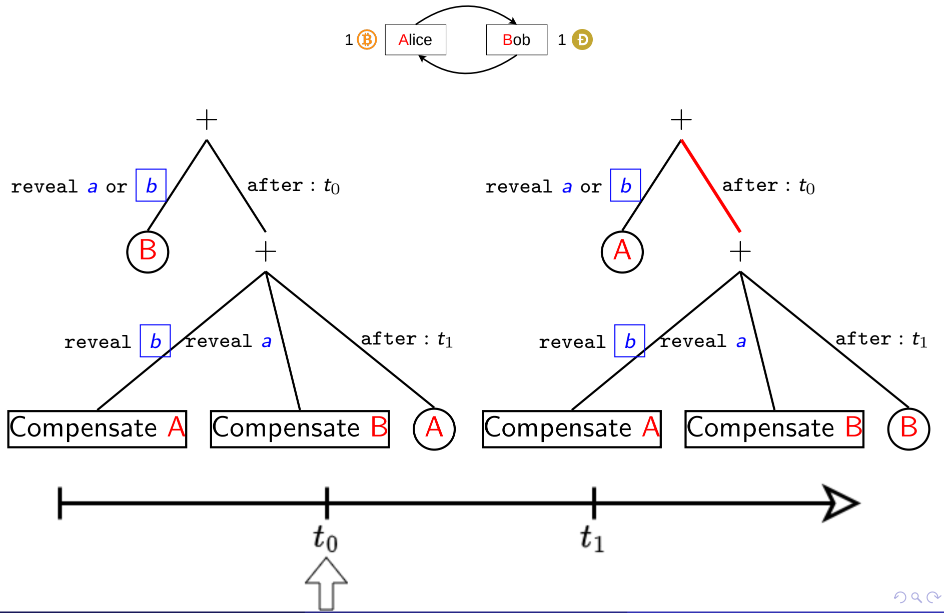

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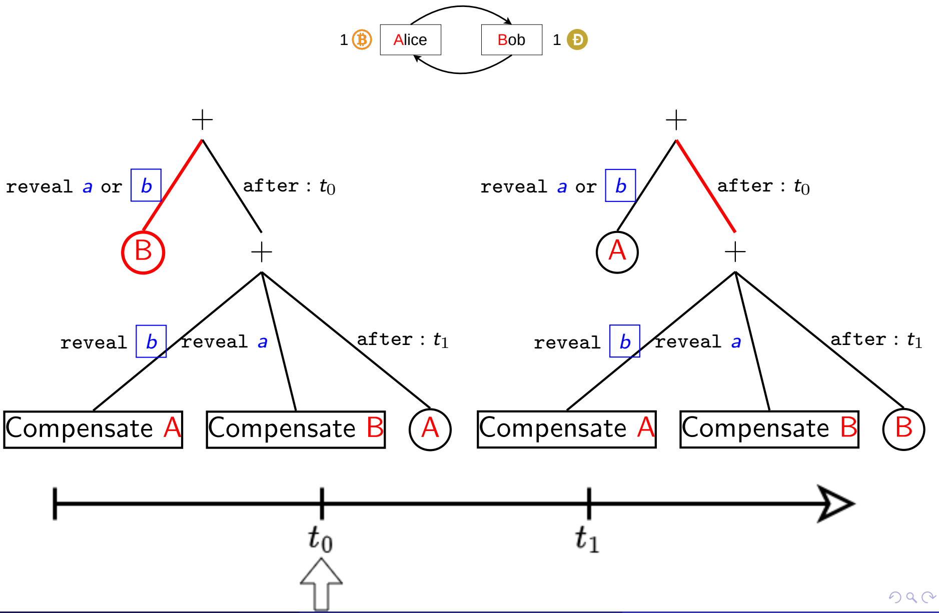

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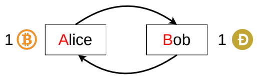

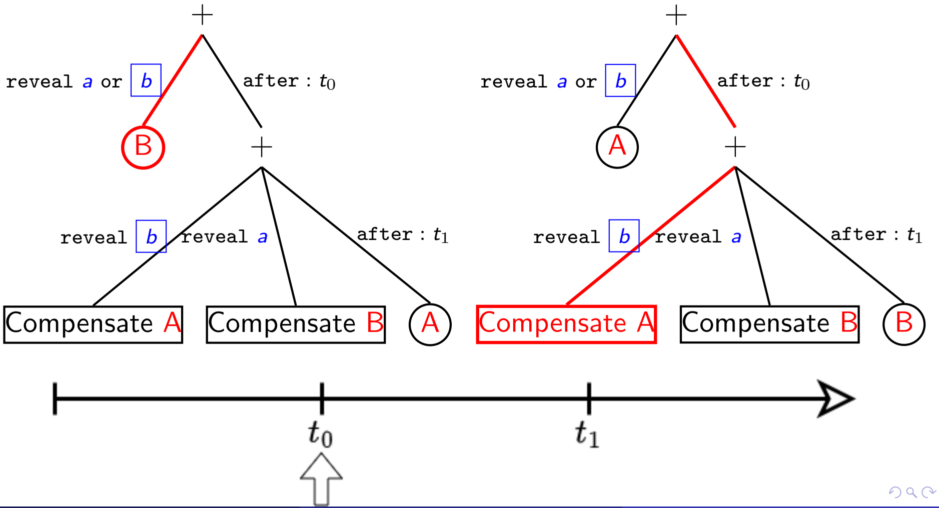

User Strategies

Suppose Alice follows a strategy S_A^x s.t.

$$S_A^x(Swap^x) = Refund^x$$

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User Strategies

Suppose Alice follows a strategy S^x_A s.t.

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$$S^x_A \xrightarrow{\text{and strategy compiler!}} \begin{cases} S^{\text{Ƀ}}_A \\ S^{\text{Ð}}_A \end{cases}$$

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Suppose Alice follows a strategy S_A^x s.t.

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$$S_A^x \xrightarrow{\text{and strategy compiler!}} \begin{cases} S_A^{₿} \\ S_A^{Đ} \end{cases}$$

$$S_A^{₿}(Swap^x_{₿}) = \texttt{if revealed } b$$
$$\texttt{then } Compensate\ A$$
$$\texttt{else wait until } Refund^x_{₿}$$

Correctness

Theorem (Compiler correctness, informal)

Each strategy of an honest user A on a BitML^x contract C translates into a strategy on the concurrently executing compiled BitML contracts $C_{Ƀ} \mid C_{Đ}$ that allows A to extract at least as many assets from $C_{Ƀ} \mid C_{Đ}$ as from C with the original strategy.

Thanks!

- BitML^x allows you to model cross-blockchain smart contracts.
- It's compiled to concurrently executing BitML contracts.
- Security by mechanisms of step secrets and collaterals.
- Work in Progress:
  - Done: BitML^{x}compiler in Haskell.
  - Currently: proving BitML^x correctness.

Download slides and PoC compiler:

Bonus 1: Adversarial Scheduling

BitML

$$C_1 + \cdots + C_k$$

- Users can always execute a valid option.
- Guaranteed to meet deadlines.
- In case of many valid options, adversary decides.

BitML^x

$$C_1^x \mathrel{+\!\!\!>} \ldots \mathrel{+\!\!\!>} C_k^x$$

- Only one valid option at a time.
- Round-based execution.
- Users can act before a subcontract is skipped.

Bonus 2: Collaterals

Every user locks, on each blockchain $\mathbb{B}$, an extra collateral deposit of value:

$$c_{\mathbb{B}} \ = \ b_{\mathbb{B}} \ \times \ (n-2)$$

where $b_{\mathbb{B}}$ is the contract balance in that blockchain, and n is the number of participants.