BitML^x

Cross-chain Smart Contracts for Bitcoin-style Cryptocurrencies

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**IMDEA Software Institute

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Introduction

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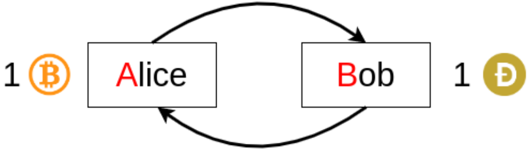
- Not all blockchains have built-in support for smart contracts.
- Bitcoin-style cryptocurrencies have limited scripting capabilities.
- BitML: high-level language for contracts on Bitcoin.
- BitML^x: cross-blockchain, synchronous, BitML.

Alice and Bob want to swap coins



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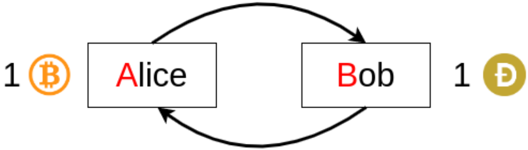

$$\{A :! 1฿ \mid A : \texttt{secret}\ a\}Swap^{฿}$$

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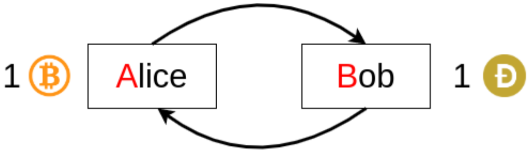

$$\{\overbrace{A :! 1\text{฿} \mid A : \texttt{secret } a}^{\text{preconditions}}\}\ \overbrace{\mathit{Swap}^{\text{฿}}}^{\text{code}}$$

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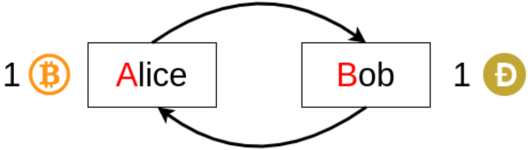

$$\{ \overbrace{\underbrace{A :! 1\text{₿}}_{\text{user deposits}} \mid \underbrace{A : \texttt{secret}\ a}_{\text{secret commitments}}}^{\text{preconditions}} \} \overbrace{\mathit{Swap}^{\text{₿}}}^{\text{code}}$$

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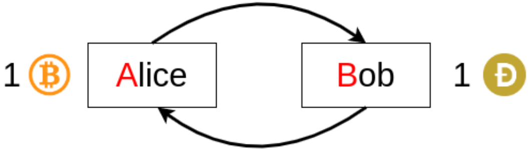

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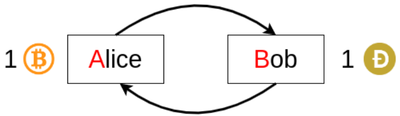
BitML example



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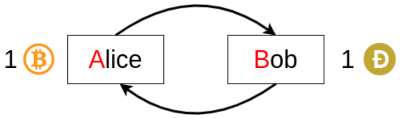

$$\{A :! 1\text{B} \mid A : \texttt{secret } a\}Swap^{\text{B}}$$

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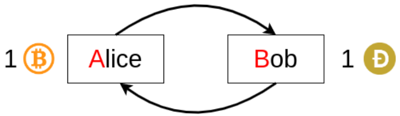
$$Swap^{\text{B}} = Exchange^{\text{B}} + Refund^{\text{B}}$$

BitML example



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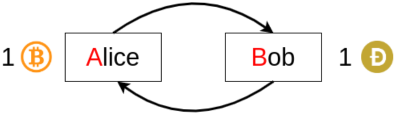

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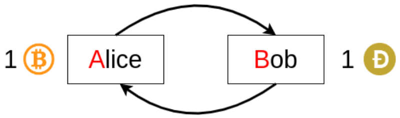

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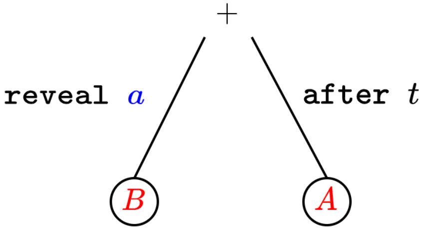
Syntax trees

Alice



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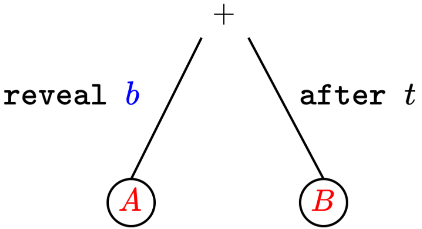
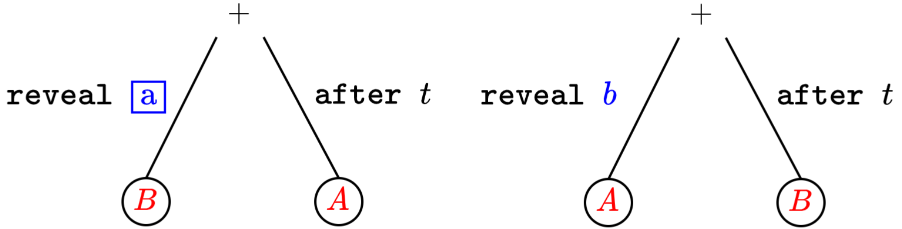


Syntax trees

Alice

- Here is $\boxed{a}$.

Bob



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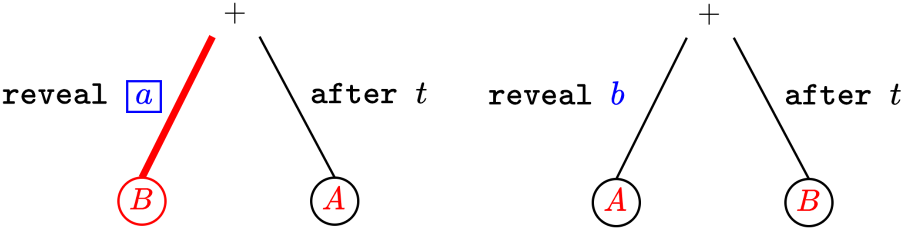

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- Here is $\boxed{a}$.
- Can I have b now?

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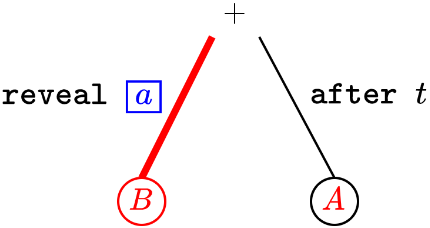
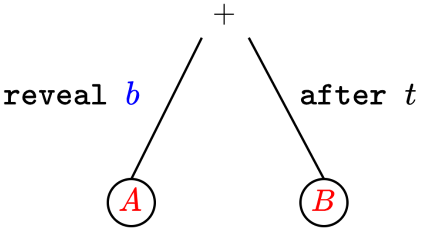
- Thanks!





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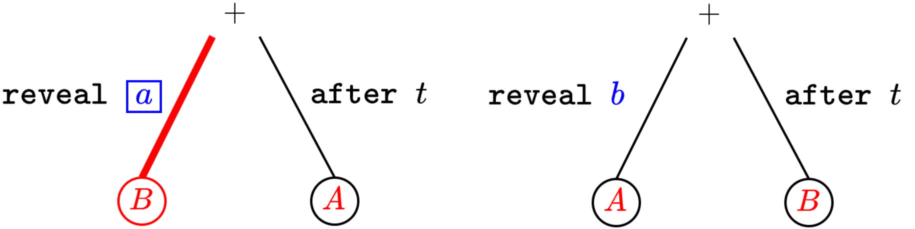

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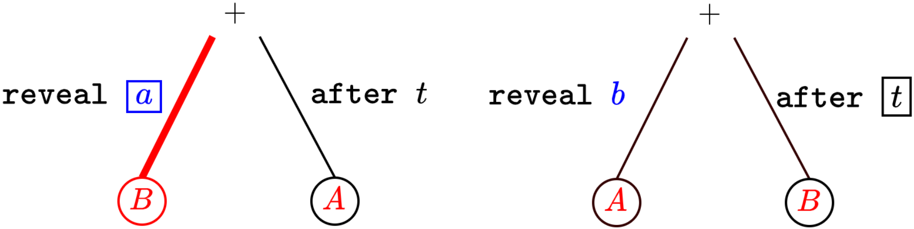

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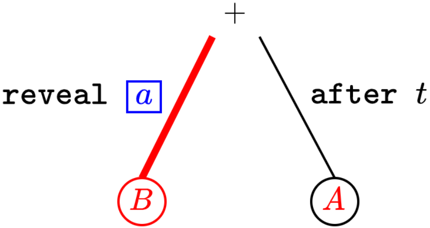

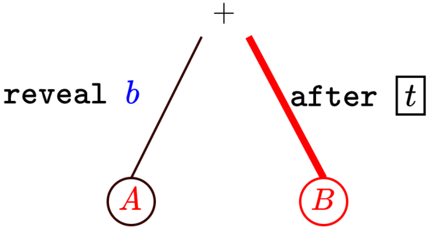

Example in BitML^x

Read the bibliography on sound cryptographic protocol designs.

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

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

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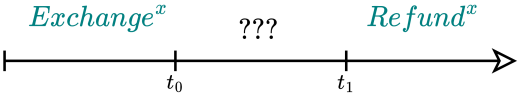

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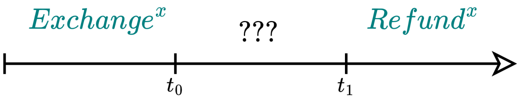
$$\{A \;:!\, (1\text{฿}, 0\text{Ð}) \mid B \;:!\, (0\text{฿}, 1\text{Ð})\}\, Swap^x$$

$$Swap^x \;=\; Exchange^x \mathrel{+\!\!\rhd} Refund^x$$



$$
\begin{aligned}
Exchange^x \;= \;& \texttt{withdraw}(\\
& \quad (0\text{฿}, 1\text{Ð}) \to A, \\
& \quad (1\text{฿}, 0\text{Ð}) \to B \\
&)
\end{aligned}
$$

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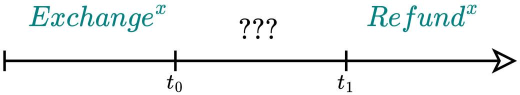

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(1\text{฿}, 0\text{Ð}) \to B \\
)
\end{aligned}
\qquad
\begin{aligned}
Refund^x \; = \texttt{withdraw}(\\
(1\text{฿}, 0\text{Ð}) \to A, \\
(0\text{฿}, 1\text{Ð}) \to B \\
)
\end{aligned}
$$

BitML^x compilation idea

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$$Swap^{฿} \xrightarrow{\text{BitML compiler}} \vec{T}_{฿}$$

$$Swap^{Đ} \xrightarrow{\text{BitML compiler}} \vec{T}_{Đ}$$

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Compilation Properties

- Synchronicity: every time a choice is taken on one side, it's replicated on the other.

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- Synchronicity is hard on the general case:

$$C_1 \not\Rightarrow C_2 \not\Rightarrow C_3 \not\Rightarrow \ldots$$

- Fairness: malicious users cannot harm honest users.

Example compilation

$\{\ A\ :!\ 1฿$
$\mid A:\ \texttt{secret}\ a$
$\mid B:\ \texttt{secret}\ b$
$\}\mathit{Swap}^{x}_{฿}$

$\{\ B\ :!\ 1Đ$
$\mid A:\ \texttt{secret}\ a$
$\mid B:\ \texttt{secret}\ b$
$\}\mathit{Swap}^{x}_{Đ}$

Example compilation

$\{$ *A* :! 1₿
$\mid$ *A* : `secret` *a*
$\mid$ *B* : `secret` *b*
$\}$*Swap*$^{x}_{₿}$

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$\mid$ *A* : `secret` *a*
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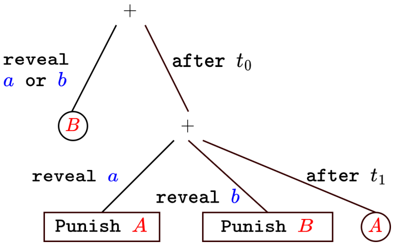
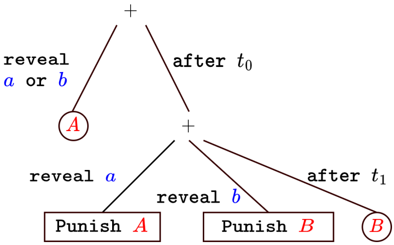
$\}$*Swap*$^{x}_{Đ}$





$$t_0 < t_1$$

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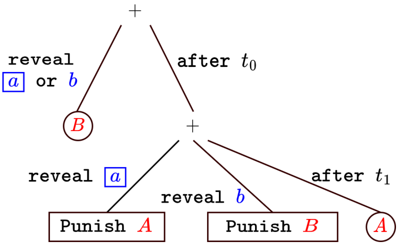

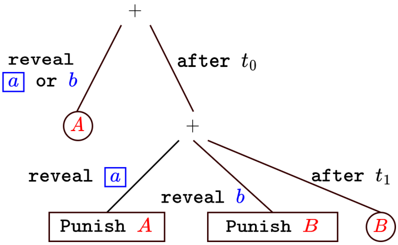

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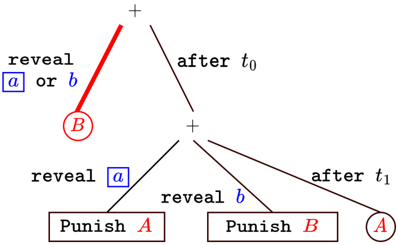

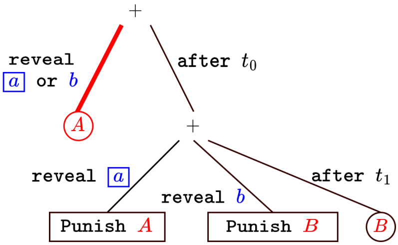

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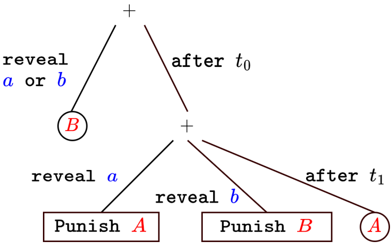

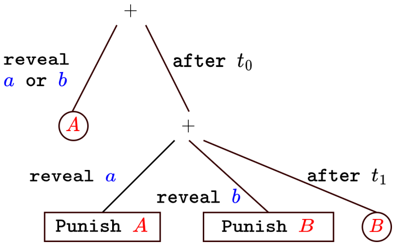

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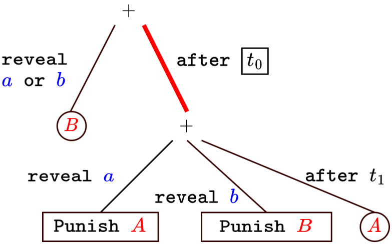

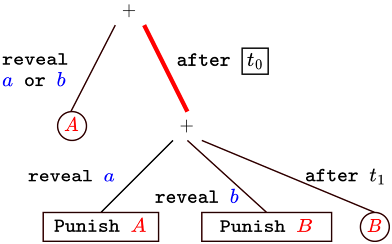

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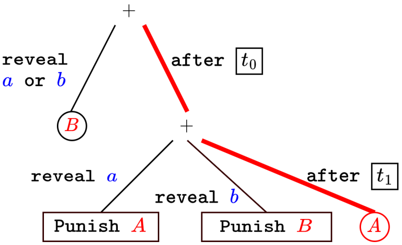

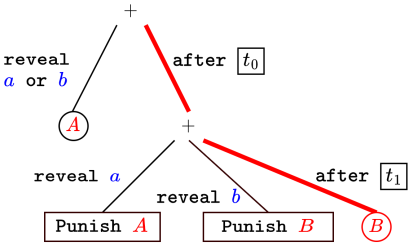

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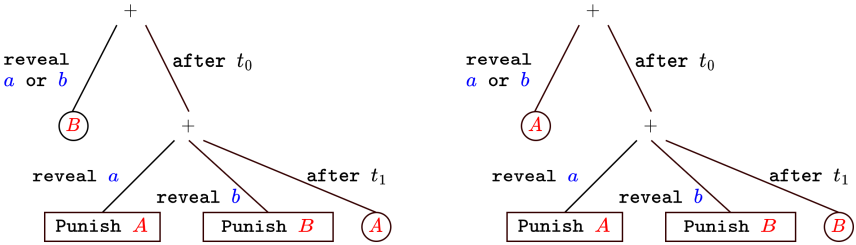

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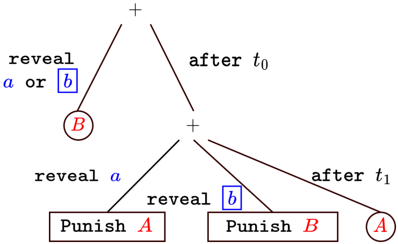

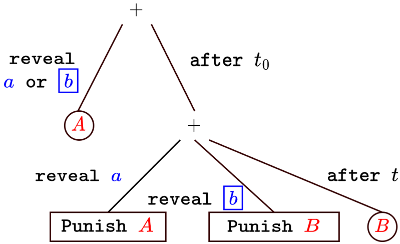

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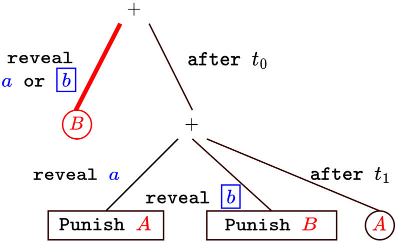
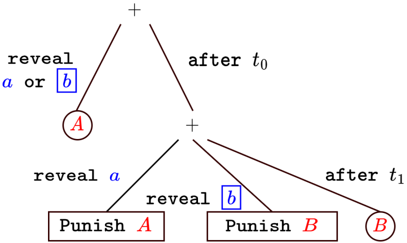


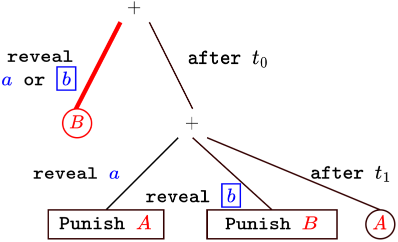


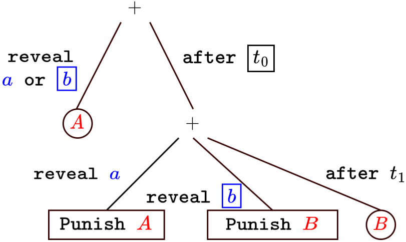
$$t_0 < t_1$$

Example compilation

$$\{\ A :!\ 1₿ \mid A : \texttt{secret}\ a \mid B : \texttt{secret}\ \boxed{b}\ \}\mathit{Swap}^{x}_{₿}$$

$$\{\ B :!\ 1Đ \mid A : \texttt{secret}\ a \mid B : \texttt{secret}\ \boxed{b}\ \}\mathit{Swap}^{x}_{Đ}$$



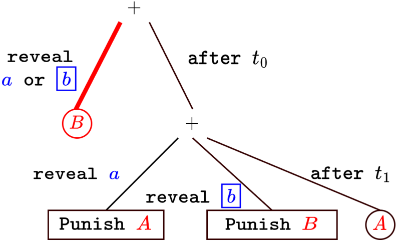


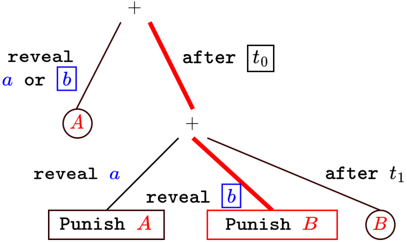
$$t_0 < t_1$$

Example compilation

$\{\ A\ :!\ 1₿$
$\mid A:\ \texttt{secret}\ a$
$\mid B:\ \texttt{secret}\ \boxed{b}$
$\}\mathit{Swap}^{x}_{₿}$

$\{\ B\ :!\ 1Đ$
$\mid A:\ \texttt{secret}\ a$
$\mid B:\ \texttt{secret}\ \boxed{b}$
$\}\mathit{Swap}^{x}_{Đ}$





$$t_0 < t_1$$

Collaterals

- How can we "punish" asynchronous behavior?

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- How can we "punish" asynchronous behavior?
- Make them pay! But, how much?
- Everyone locks in an extra collateral deposit c:

$$c = b \times (n - 2)$$

where b is the contract balance, an n is the number of participants.

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 $C_{\text{₿}} \mid C_{\text{Ð}}$ that allows A to extract at least as many assets from $C_{\text{₿}} \mid C_{\text{Ð}}$ 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 timed commitments and punishments
- Work in Progress:
  - Proving BitML^x correctness.
  - Implementing compiler in Haskell.

Download short paper, slides and (soon) compiler:

Bonus: standard atomic swaps