Compile Jif Programs for Distributed Systems

[ZZNM 01, ZCMZ 03]

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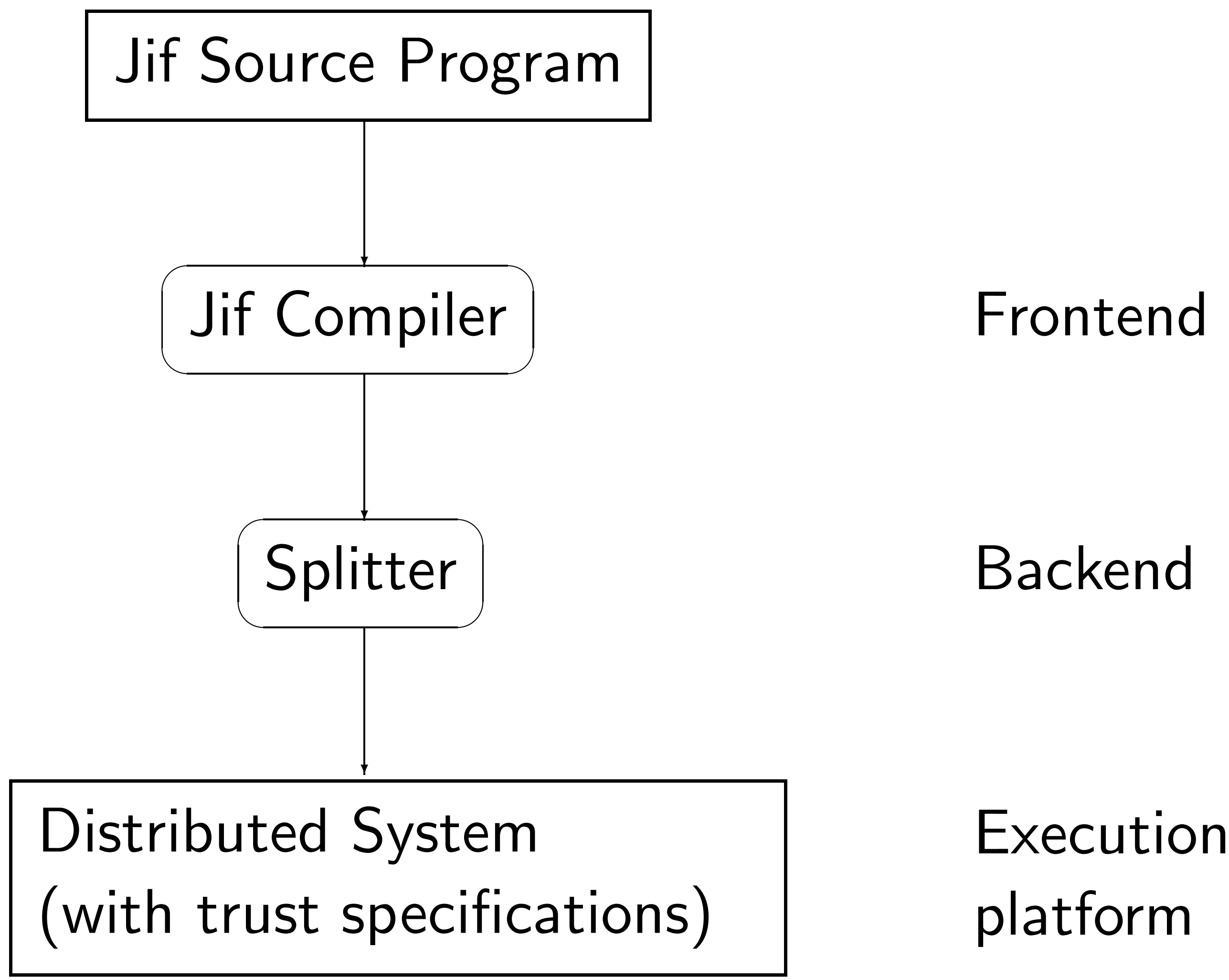
Problem

- Jif: well-typed programs are secure. (Wow!)
- But the execution platform is in TCB.
  - Do we have to trust Microsoft Windows?
  - What if my laptop is stolen?
- Let users decide: blue pill or red pill.
  - Users bear the risks associated with their decisions.
- What if there is no single host trusted by all the participating users (principals) of a program?

Distributed Systems as the Platform: Opportunity and Challenge

- Potential to be more secure
  - Decentralized trustiness
    - Run Alice's code on Alice's host, and run Bob's code on Bob's host.
  - Boost security: replication, secret sharing.
  - Avoid single point of failure.
- Weaker assumption: partial failure is a given.
  $\longrightarrow$ requires fault detection or tolerance
- Synchronization

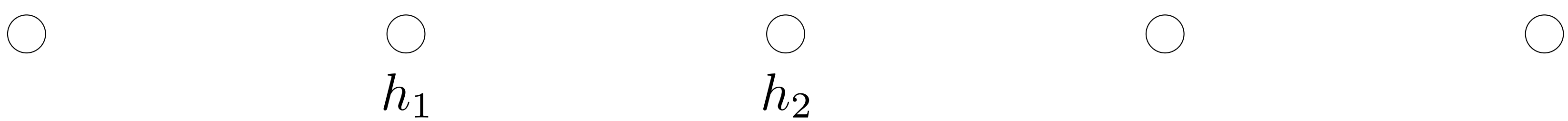
Architecture



A Simple Example

$$x = a + b$$

- x, a and b: trusted by Alice and Bob.
- h_1: trusted by Alice
- h_2: trusted by Bob



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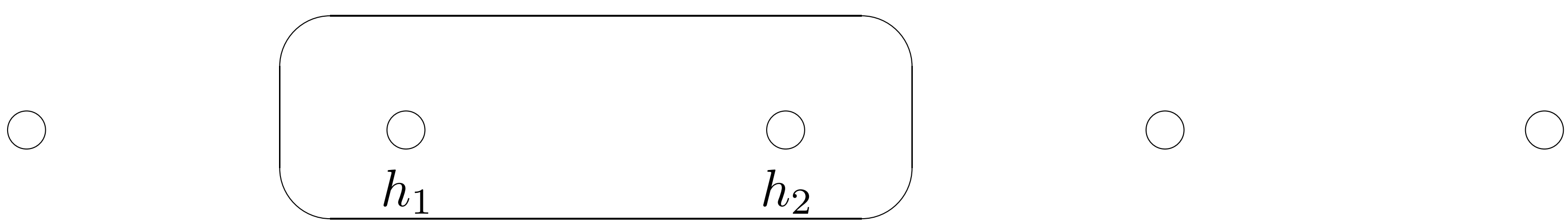

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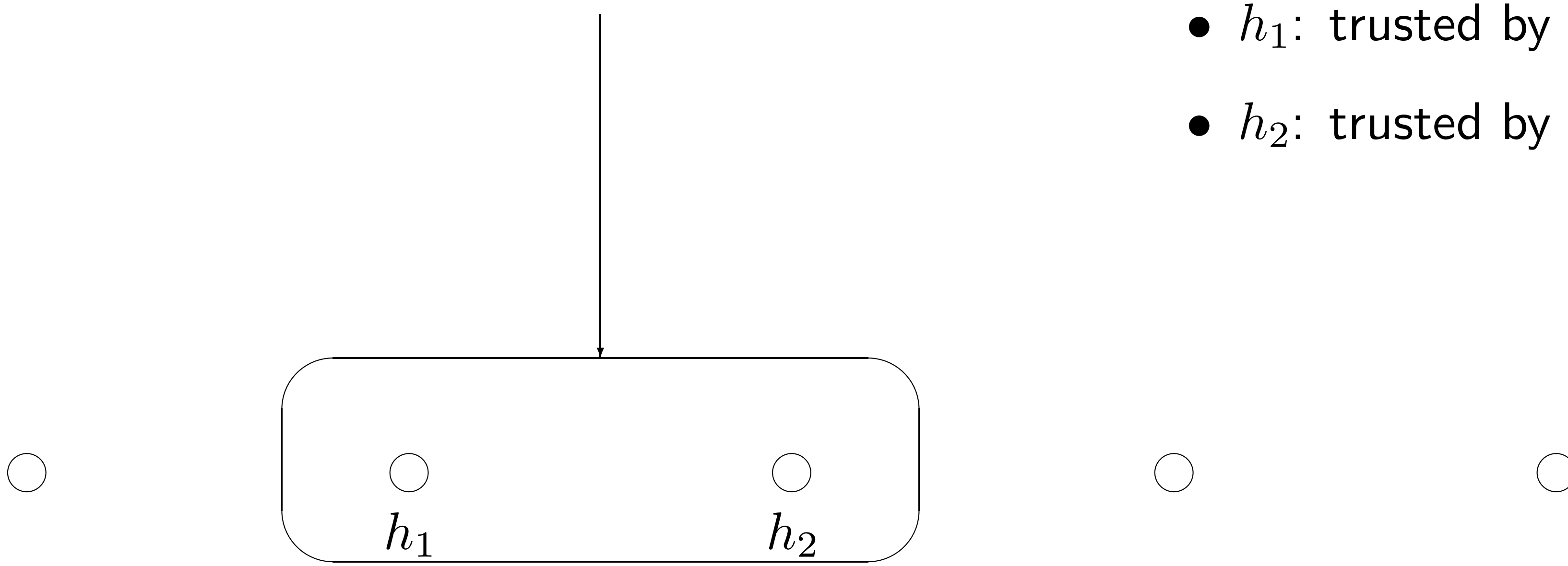

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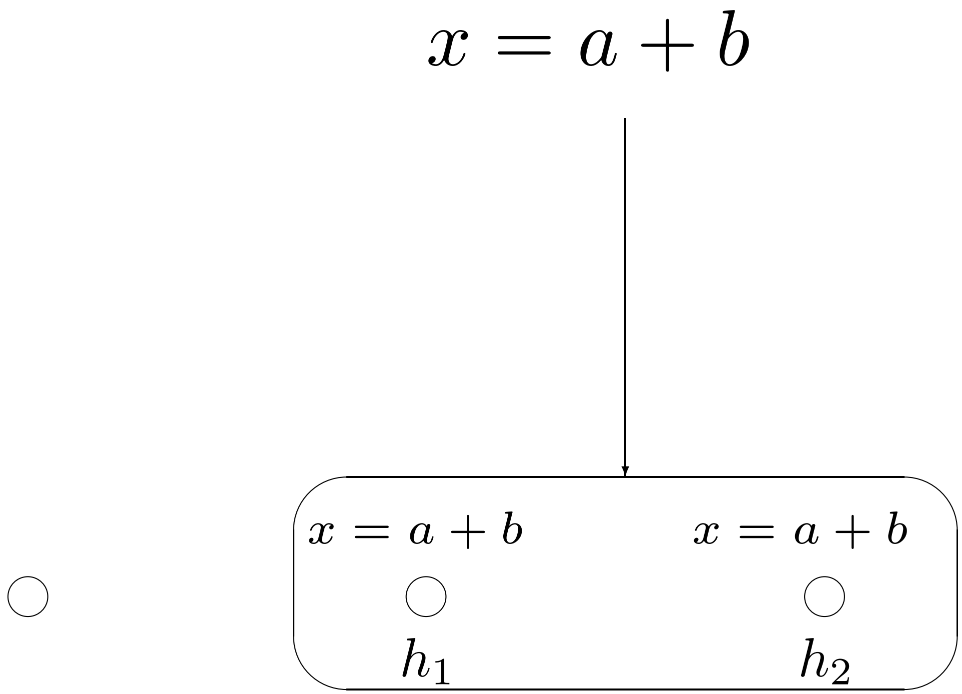

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Overview of Code Generation

- Phase 1: $[\![e_1; \ldots; e_n]\!] = e_1@H_1; \ldots; e_n@H_n$
  - H_i is trusted to run e_i: $P(H_i) \leq P(e_i)$
  - H_i is a virtual host.

    $\longrightarrow$ provides a hook for applying replication.

- Phase 2: $[\![e_i@H_i]\!] = e_{i1}@h_1 \parallel \ldots \parallel e_{im}@h_m$.

- Phase 3: insert calls to the run-time system after e_{ij}
  - Transfer control between hosts
  - Transfer data between hosts

Virtual Host

- Single host [ZZNM, SOSP 01]
- Simple replication (with hashing) [ZCMZ, Oakland 03]
- Quorum systems [future work]
- Secret sharing [future work]

Security Labels and Hosts

- General security policy: $\{o : f_1, \ldots, f_n\}$.
  - You can only hurt by friends.
  - Confidentiality labels: $\{o : r_1, \ldots, r_n\}$.
  - Integrity labels: $\{o : w_1, \ldots, w_n\}$
- Host labels: the trustworthiness of hosts.
  - E.g. $C(h) = \{o : A, B\}$ and $I(h) = \{o : A\}$

Simple Replication with Hash

- Replication increases integrity.
  - Replicate data d on h_1 and h_2.
  - Replicas need to be consistent.
  - $H = \{h_1, h_2\}$: $I(H) = I(h_1) \sqcap I(h_2)$
  - Sufficient trustiness: $I(H) \sqsubseteq I(d)$
  - E.g. $I(d) = \{o : congress\}$, $I(h_1) = \{o : senate\}$, $I(h_2) = \{o : house\}$.
- Replication may jeopardize confidentiality.
  - E.g. $C(d) = \{o : senate\}$
  - $h_1 \leftarrow d \qquad h_2 \leftarrow md5(d, nonce)$
  - $H = \langle\{h_1, h_2\}, \{h_2\}\rangle$: $I(H) = I(h_1) \sqcap I(h_2) \quad C(H) = C(h_1)$.
  - Implicit flow: $C_{if}(H) = C(h_1) \sqcap C(h_2)$

Replicating Computation

- $H = \{h_1, \ldots, h_n\}$
  $\longrightarrow [\![e@H]\!] = e@h_1 \parallel \ldots \parallel e@h_n$

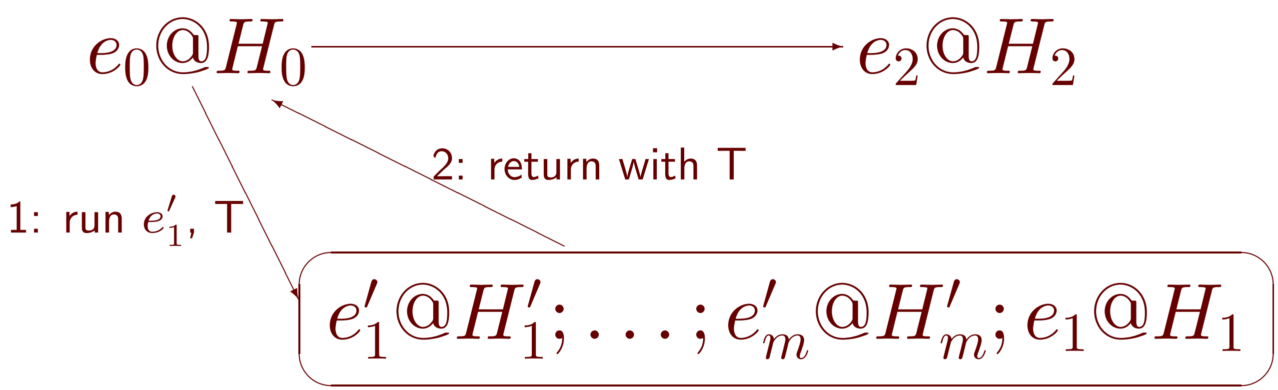
- $H = \langle \{h_1, \ldots, h_n\}, \{h_{i1}, \ldots, h_{im}\} \rangle$
  - If e is $x = y$, then $[\![e@H]\!] = e@h_1 \parallel \ldots \parallel e@h_n$.
  - Otherwise, $e@H$ cannot be compiled.

Run-time System: Control Transfer (I)

- $e_1@H_1 \longrightarrow e_2@H_2$
  - H_1 sends a request (run e_2) to H_2.
  - H_2 checks $I(H_1) \sqsubseteq I(e_2)$.
- Simple replication: $H_1 = \{h_1, \ldots, h_n\} \quad H_2 = \{h'_1, \ldots, h'_m\}$
  - $h_1, \ldots, h_n$ send the request to h'_j.
  - h'_j checks G_j: $\bigsqcap_{1 \leq i \leq n} I(h_i) \sqsubseteq I(e_2) \sqcup I(h'_j)$.
- Correctness: $G_1 \wedge \ldots \wedge G_m \Rightarrow I(H_1) \sqsubseteq I(e_2)$

Run-time System: Control Transfer (II)

- What if $I(e_1) \not\sqsubseteq I(e_2)$?
- Consider the whole control flow: $\ldots e_0; e'_1; \ldots; e'_m; e_1; e_2$.
  - $I(e_0) \sqsubseteq I(e_2)$ and $\forall i \in [1..m]\ I(e'_i) \not\sqsubseteq I(e_2)$



- Simple replication: $H_1 = \{h_1, \ldots, h_n\}$
  - Each h_i generates a token t_i.
  - $T = \{t_1, \ldots, t_n\}$
  - Return to h_i by presenting t_i.

Conclusion

- Hypothesis: it's impossible or too expensive to implement a provably secure platform.
- Key ideas:
  - Let users specify the trustworthiness of hosts and take the corresponding risk.
  - Use distributed systems as the platform.

    $\rightarrow$ analyze and apply existing techniques: replication, secure hashing, nonces...
- Technical contributions: splitter, run-time protocols.