A theory of DbC for multiparty distributed interactions

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Aims & Objectives

- Support description/engineering of multiparty protocols
  - format of messages
  - discipline interactions in conversations
  - values carried in messages
- Devise a theoretical framework
  - analyze protocols
  - specify obligations/guarantees of participants

Reading list

- Assertion methods

C. A. R. Hoare
An axiomatic basis of computer programming
In CACM, 12, 1969.

- Design by Contract (DbC)

B. Meyer
Applying "Design by Contract"
In Computer (IEEE), 25, 1992.

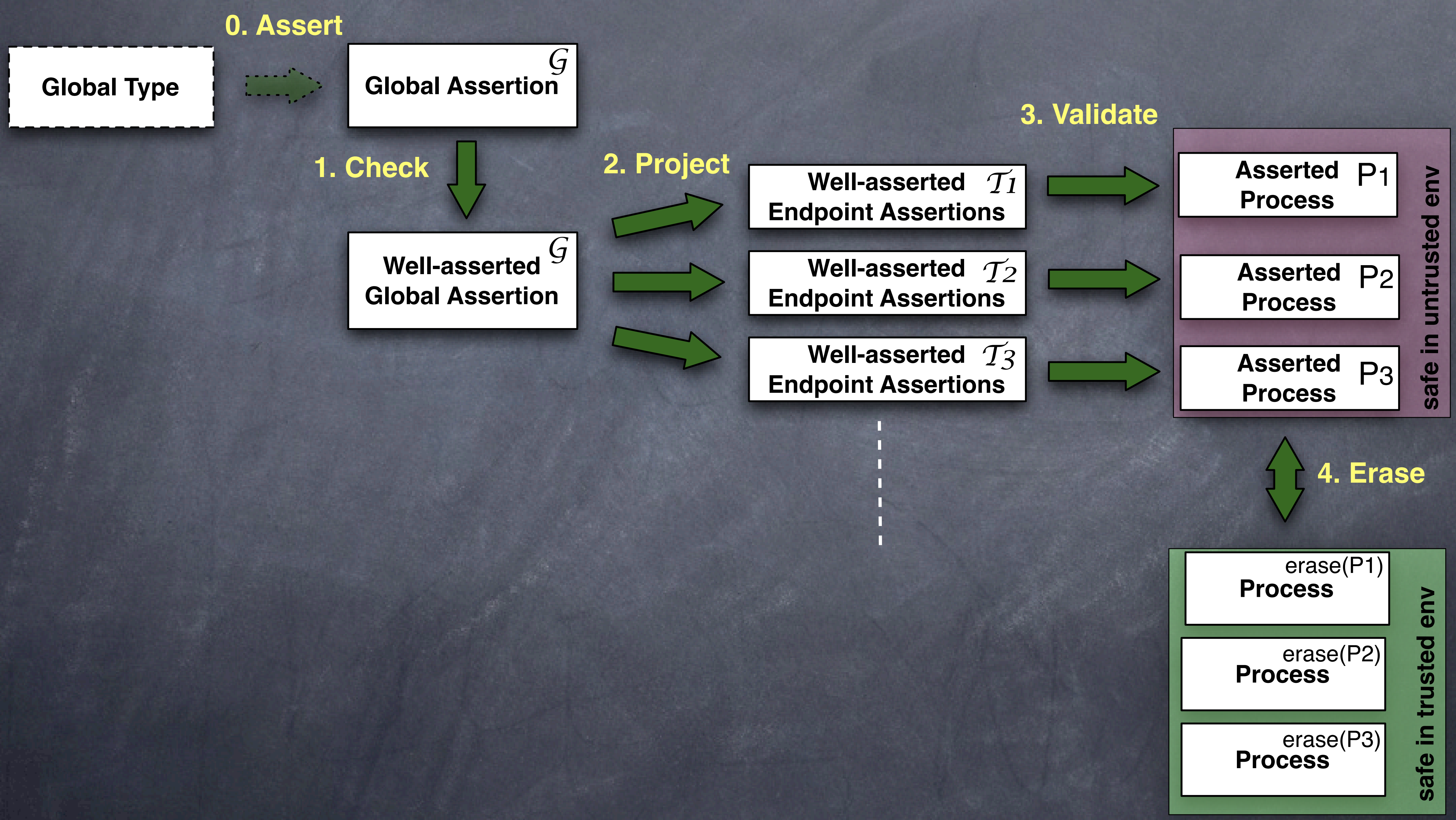
- Multiparty Asynchronous Session Types

K. Honda, N. Yoshida and M. Carbone
Multyparty Asynchronous Session Types
In POPL 2008.

- Global assertions

L. Bocchi, K. Honda, E. Tuosto, and N. Yoshida
A theory of DbC for multiparty distributed
http://www.cs.le.ac.uk/people/lb148/assertedtypes.html

Outline



Global Type
0. Assert
Global Assertion $\mathcal{G}$
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safe in untrusted env
4. Erase
erase(P1) Process
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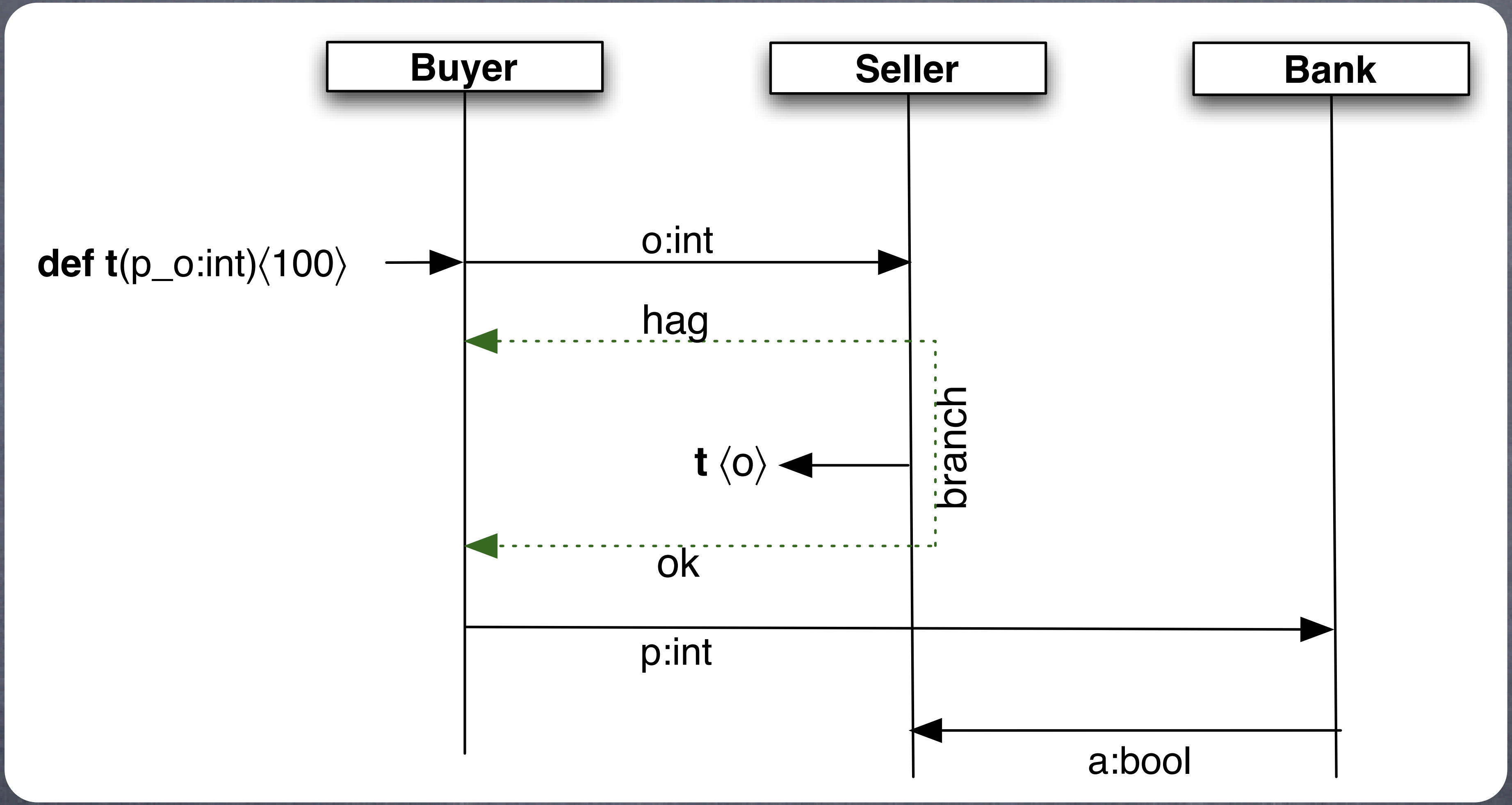
safe in trusted env

Design by Contract

- Type signatures to constraint computation
  - the method m of an object of class C should be invoked with a string and an integer; m will return (if ever) a string
- DbC = Types + Assertions
  - if m is invoked with a string representing a date $2007 \leq d \leq 2008$ and an integer $n \leq 1000$ then it will (if ever) return the date n days after d
- In a distributed setting each party has
  - guarantees (e.g., on the content of the received messages)
  - obligations (e.g., on the content of the sent messages)

A simple global type



μ t(p_o : int)⟨100⟩.
Buyer → Seller : ChSeller (o : int).
Seller → Buyer : ChBuyer {
ok: Buyer → Bank : ChBank (p : int). Bank → Seller : ChSeller(a : bool),
hag: t⟨o⟩
}

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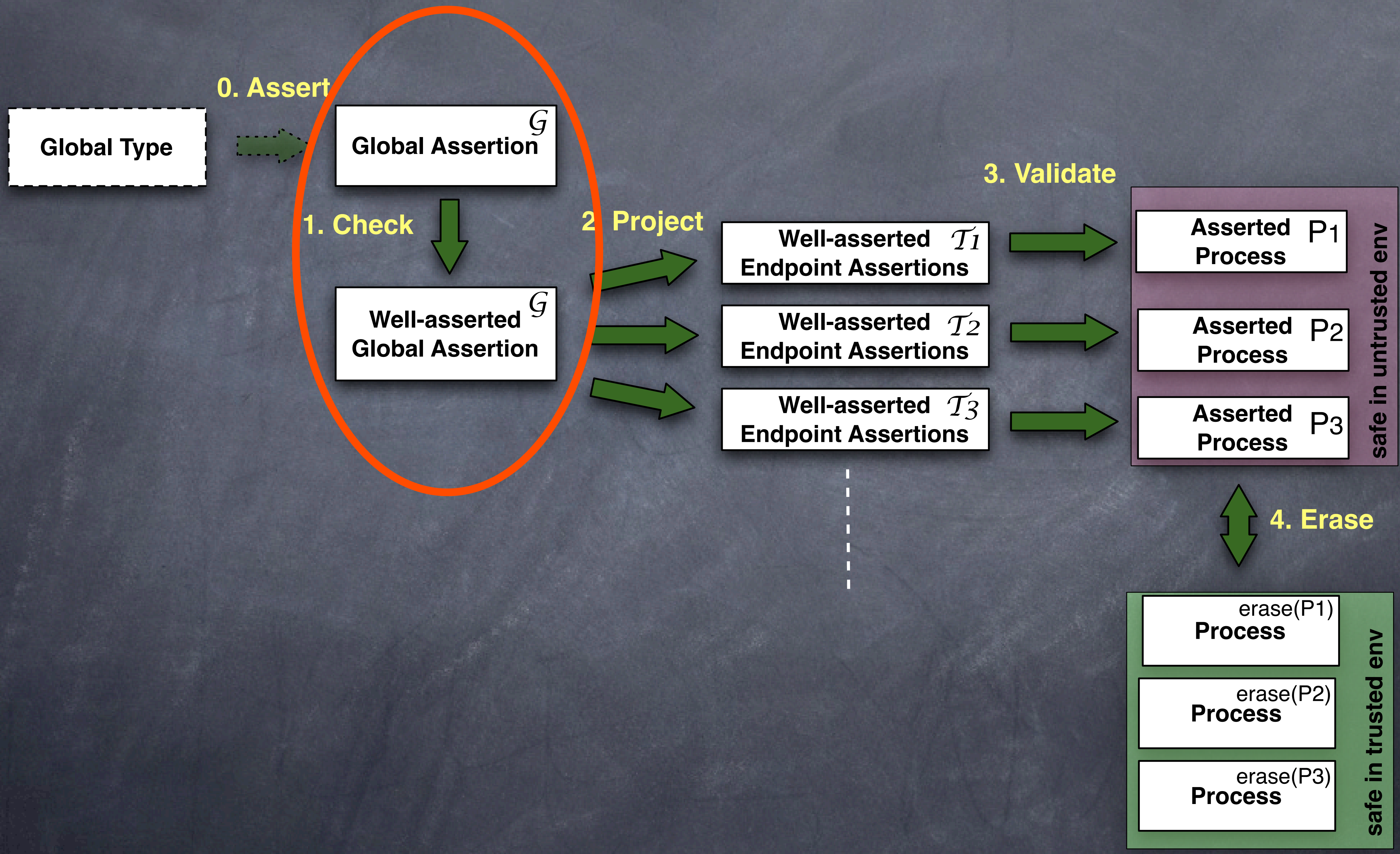

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Syntax for Global Assertions

$$
\begin{array}{lll}
\mathcal{G} & ::= & \mathtt{p} \to \mathtt{p}' : k\ (\tilde{v} : \tilde{S})\{A\}.\mathcal{G} \\
& \mid & \mathtt{p} \to \mathtt{p}' : k\ \{\{A_j\}l_j : \mathcal{G}_j\}_{j \in J} \\
& \mid & \mu\ \mathbf{t}(\ldots v_i : S_i\ @\ \mathtt{L_i} \ldots)\langle \tilde{e} \rangle \{A\}.\mathcal{G} \\
& \mid & \mathbf{t}\langle \tilde{e} \rangle \\
& \mid & \mathcal{G}, \mathcal{G}' \\
& \mid & \mathsf{end}
\end{array}
$$

$$
\begin{array}{lll}
S & ::= & \mathsf{bool} \mid \mathsf{int} \mid \ldots \mid \mathcal{G} \\
\mathtt{L} & ::= & \{\mathtt{p}, \mathtt{p}'\}
\end{array}
$$

What is A?

Logical Language

- The investigation of the most suitable logic is left as a future work
  - The logical language is likely to be application dependent
- good candidates are first-order decidable logics (e.g. Presburger arithmetic)

$$A \quad ::= \quad e_1 = e_2 \ | \ e_1 > e_2 \ | \ \phi(e_1, \ldots, e_n) \quad | \quad A_1 \wedge A_2 \ | \ \neg A \ | \ \exists v(A)$$

A global assertion

G_{hag} = μ t(o : int@{Buyer, Seller})⟨10⟩{o≥10}.

Buyer → Seller: ChSeller (p : int) {p≥10}.

Seller → Buyer: ChBuyer{

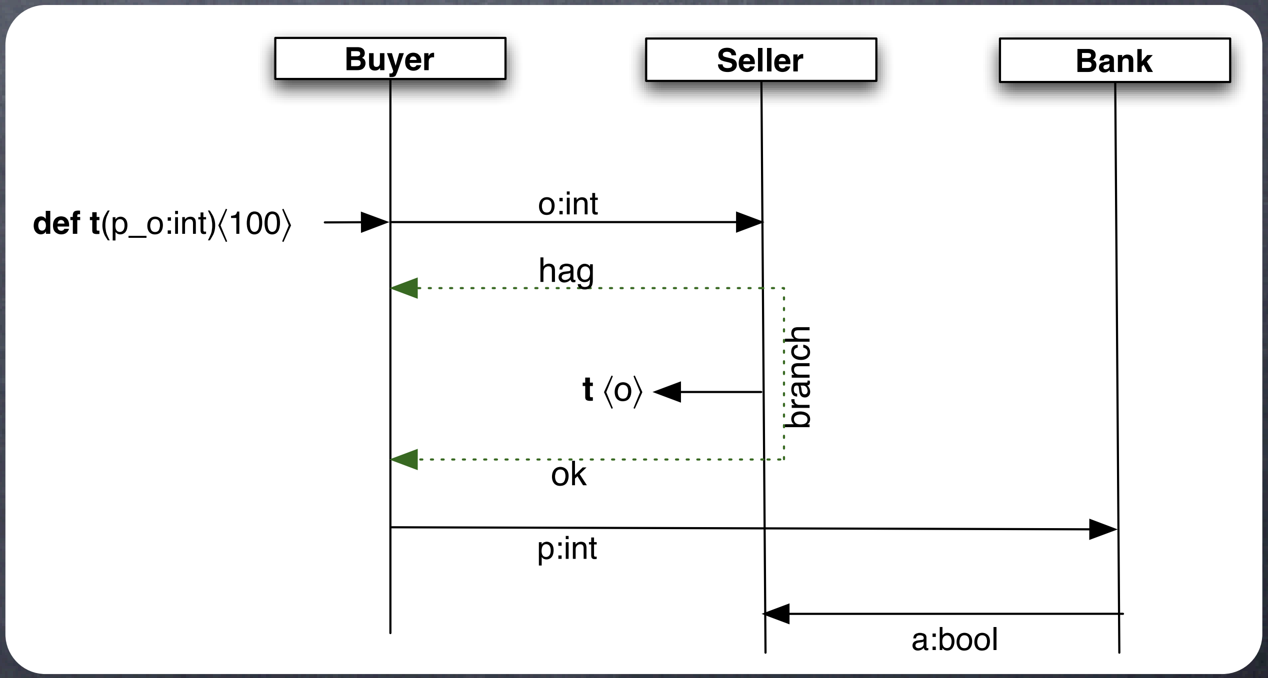
{true} ok:

Buyer → Bank: ChBank (c : int) {c=p}.

Bank → Seller: ChSeller (a : bool) {true},

{p>o} hag: t⟨p⟩

}



Correctness of Global Assertions

- Global assertions must respect 3 principles
  - History sensitivity
  - Locality
  - Temporal satisfiability

History sensitivity principle

An interaction predicate can only constraint variables known by the sender

~~Alice → Bob : ChB (u:int) {true}.~~
~~Bob → Carol : ChC (v:int) {true}.~~
~~Carol → Alice : ChA (z:int) {z<u}~~

Carol cannot guarantee z<u as she doesn't know u

Alice → Bob : ChB (u:int) {true}.
Bob → Carol : ChC (v:int) {v<u}.
Carol → Alice : ChA (z:int) {z<v}

z indirectly depends on u...

...but Carol can choose the right value since she knows v and the predicates ensure that the dependencies are respected

Locality principle

Predicates can only constraint variables which they introduce

~~Alice → Bob : ChB (u:int) {u>0}.~~
~~Bob → Carol : ChC (v:int) {true}.~~
~~Carol → Alice : ChA (z:int) {z≥v ∧ v>1}~~

Carol strengthens the constraints on v withough being entitled

Alice → Bob : ChB (u:int) {u>0}.
Bob → Carol : ChC (v:int) {true}.
Carol → Alice : ChA (z:int) {z≥v ∧ z>1}

Temporal-satisfiability principle

- For each value satisfying a predicate A
  - there is always a branch enabled
  - for each subsequent predicate A′, it is always possible to find values that satisfy A′

Alice → Bob : ChB (u:int) {u<10}.
Bob → Alice : ChA (v:int) {v<u ∧ v>6}

had Alice sent 6 or 7, Bob couldn't meet his obbligation!

Being true to our principles

- HSP can be statically checked

$$\frac{\Gamma, \tilde{v} : \tilde{S} \,@\, \{\mathtt{p}, \mathtt{p}'\} \vdash \mathcal{G} \;\; \forall u \in var(A) \setminus \tilde{v}, \Gamma \vdash u \,@\, \mathtt{p}}{\Gamma \vdash \mathtt{p} \to \mathtt{p}' \colon k\; (\tilde{v} : \tilde{S})\{A\}.\mathcal{G}} \qquad \frac{\forall j \in J,\; \Gamma \vdash \mathcal{G}_j \;\; \forall u \in \bigcup_{j \in J} var(A_j) \Gamma \vdash u \,@\, \mathtt{p}}{\Gamma \vdash \mathtt{p} \to \mathtt{p}' \colon k\; \{\{A_j\} l_j : \mathcal{G}_j\}_{j \in J}}$$

$$\frac{\Gamma \vdash \mathcal{G} \quad \Gamma \vdash \mathcal{G}'}{\Gamma \vdash \mathcal{G}, \mathcal{G}'} \qquad \frac{}{\Gamma \vdash \mathsf{end}} \qquad \frac{\Gamma \vdash e_1 : S_1 \,@\, \mathtt{L_1} \;\; \cdots \;\; \Gamma \vdash e_n : S_n \,@\, \mathtt{L_n}}{\Gamma, \mathbf{t} : S_1 \,@\, \mathtt{L_1} \ldots S_n \,@\, \mathtt{L_n} \vdash \mathbf{t}\langle \tilde{e} \rangle}$$

$$\frac{\Gamma' = \Gamma, \mathbf{t} : S_1 \,@\, \mathtt{L_1} \ldots S_n \,@\, \mathtt{L_n} \quad \Gamma' \vdash \mathcal{G} \quad dom(\Gamma') \supseteq var(A) \quad \forall i. \Gamma \vdash v_i : S_i \,@\, \mathtt{L_i}, e_i : S_i \,@\, \mathtt{L_i}}{\Gamma \vdash \mu \mathbf{t} \langle \tilde{e} \rangle (v_1 : S_1 \,@\, \mathtt{L_1}, \ldots, v_n : S_n \,@\, \mathtt{L_n})\{A\}.\mathcal{G}}$$

Being true to our principles

- TSP implies LP, and we give a checker GSat(G,A)

1. $\mathcal{G} = \mathtt{p}_1 \to \mathtt{p}_2 \colon k(\tilde{v} : \tilde{S})\{A'\}.\mathcal{G}' \begin{cases} \text{if } A \supset \exists \tilde{v}(A') \text{ then } GSat(\mathcal{G}, A) = GSat(\mathcal{G}', A \wedge A') \\ \text{otherwise } GSat(\mathcal{G}, A) = \mathsf{false} \end{cases}$

1. $\mathcal{G} = \mathtt{p}_1 \to \mathtt{p}_2 \colon k\,(\tilde{v} : \tilde{S})\{A'\}.\mathcal{G}'$

$$\begin{cases} \text{if } A \supset \exists \tilde{v}(A') \text{ then } GSat(\mathcal{G}, A) = GSat(\mathcal{G}', A \wedge A') \\ \text{otherwise } GSat(\mathcal{G}, A) = \mathsf{false} \end{cases}$$

2. ...

6. $\mathcal{G} = \mathsf{end}$ then $GSat(\mathcal{G}, A) = \mathsf{true}$

Well-assertedness

- A global assertion G is well-asserted when
  - G is history-sensitive and
  - GSat(G,true) = true

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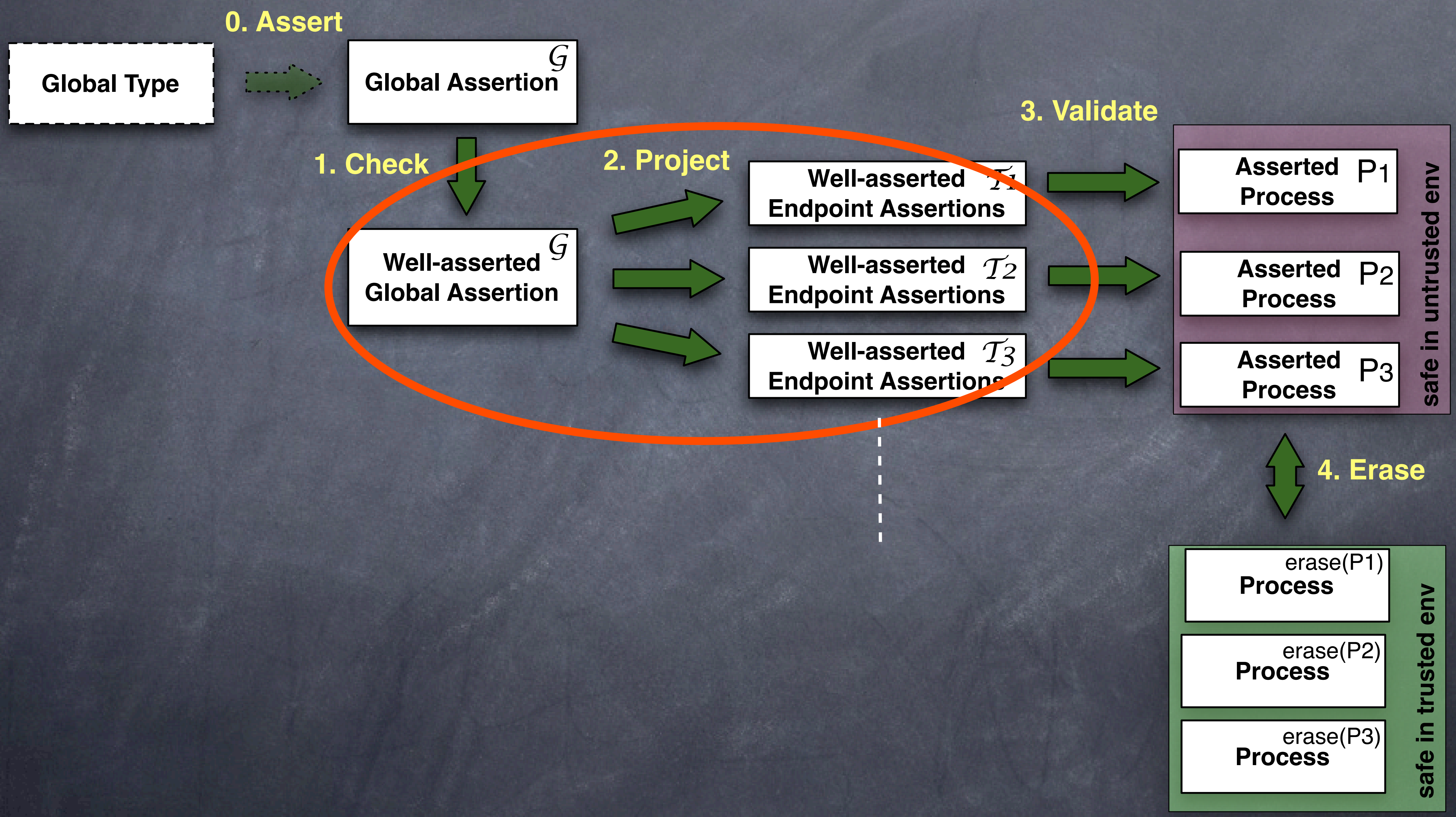

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End-point assertions

$$
\begin{array}{lcl}
\mathcal{T} & ::= & k!(\tilde{v} : \tilde{S})\{A\};\mathcal{T} \\
 & \mid & k?(\tilde{v} : \tilde{S})\{A\};\mathcal{T} \\
 & \mid & k \oplus \{\{A_j\}l_i : \mathcal{T}_i\}_{i\in I} \\
 & \mid & k\&\{\{A_i\}l_i : \mathcal{T}_i\}_{i\in I} \\
 & \mid & \mu\mathbf{t}\langle\tilde{e}\rangle(\tilde{v} : \tilde{S})\{A\}.\mathcal{T} \\
 & \mid & \mathbf{t}\langle\tilde{e}\rangle \\
 & \mid & \mathsf{end}
\end{array}
$$

Endpoint assertions specify the behaviour of processes involved in a session.

Projections & “third parties”

Seller → Buyer : ChBuyer(p : int) {p > 10}.

Buyer → Bank : ChBank (c : int) {c ≥ p}

A too naive projection wrt Bank would give

ChBank?(c:Int) {c ≥ p}

which is meaningless because Bank ignores the value of p so it cannot check if Buyer meets its obbligation.

Projecting global assertions

$$Proj(\mathtt{p}_1 \to \mathtt{p}_2 \colon k\,(\tilde{v} : \tilde{S})\{A\}.\mathcal{G}', A_{Proj}, \mathtt{p}) = \begin{cases} k!(\tilde{v} : \tilde{S})\{A\}.\mathcal{G}_{Proj} & \text{if } \mathtt{p} = \mathtt{p}_1 \\ k?(\tilde{v} : \tilde{S})\{\exists V_{ext}(A \wedge A_{Proj})\}.\mathcal{G}_{Proj} & \text{if } \mathtt{p} = \mathtt{p}_2 \\ \mathcal{G}_{Proj} & \text{otw} \end{cases}$$

$$\mathcal{G}_{Proj} = Proj(\mathcal{G}', A \wedge A_{Proj}, \mathtt{p}) \text{ and } V_{ext} = var(A_{Proj}) \setminus \mathcal{I}(\mathcal{G}) \restriction \mathtt{p}$$

Seller → Buyer : ChBuyer(p : int) {p > 10}.

Buyer → Bank : ChBank (c : int) {c ≥ p}

projected wrt **Bank**

ChBank?(c:Int) {∃p. p≥10 ∧ c ≥ p}

Projection in action

T_{hag} = μ t(o : int)⟨10⟩ {o≥10}.

ChSeller?(p : int) {p≥10 ∧ o≥10};

ChBuyer⊕{

{true} ok: ChSeller?(a : bool) {∃c. p≥10 ∧ o≥10 ∧ c=p}

{p>o} hag: t⟨o⟩,

}

G_{hag} = μ t(o : int@{Buyer, Seller})⟨10⟩{o≥10}.

Buyer → Seller: ChSeller (p : int) {p≥10}.

Seller → Buyer: ChBuyer{

{true} ok:

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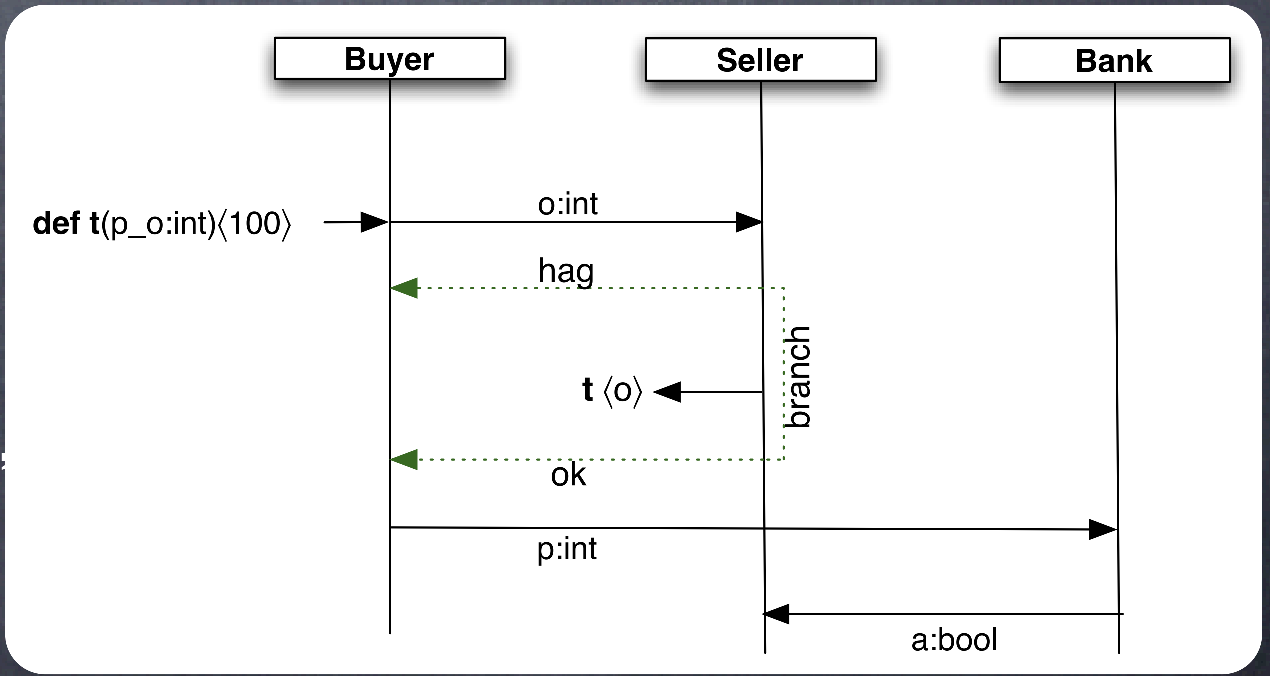

Well-assertedness for endpoint assertions

- Similarly to global assertions, we define LSat(T,A) to check if T is satisfiable under assertion A
  - Notice that for endpoint assertions only TSP is important as
    - TSP implies LP
    - HSP is vacuously guaranteed
- Proj(G,true,p) preserves well-assertedness

Asserted processes

$P ::= \overline{a}[2..n]\,(\tilde{s}).P$	request		$\mid \mathsf{if}\ e\ \mathsf{then}\ P\ \mathsf{else}\ Q$	conditional
$\mid a[p]\,(\tilde{s}).P$	accept			error
$\mid s!\langle\tilde{e}\rangle(\tilde{v})\{A\}; P$	send		$\mid P \mid Q$	parallel
$\mid s?(\tilde{v})\{A\}; P$	reception		$\mid \mathbf{0}$	idle
$\mid s \lhd \{A\}l; P$	select		$\mid (\nu a)P$	hiding
$\mid s \rhd \{\{A_i\}l_i : P_i\}_{i\in I}$	branch		$\mid \mathsf{def}\ D\ \mathsf{in}\ P \mid X\langle\tilde{e}\tilde{s}\rangle$	rec def/call
$D ::= \{\langle X_i(\tilde{v}_i\tilde{s}_i) = P_i\rangle\}_{i\in I}$	rec dec		$n ::= a \mid \mathsf{true} \mid \mathsf{false}$	values
$e ::= n \mid e \wedge e' \mid \neg e\ \ldots$	expressions			

Semantics

$$\overline{a}[2..\mathtt{n}]\,(\tilde{s}).P \mid a[2]\,(\tilde{s}).P_2 \mid \ldots \mid a[\mathtt{n}]\,(\tilde{s}).P_n \to (\nu\tilde{s})(P_1 \mid P_2 \mid \ldots \mid P_n \mid s_1 : \emptyset \mid \ldots \mid s_n : \emptyset)$$

$$s!\langle\tilde{e}\rangle(\tilde{v})\{A\}; P \mid s : \tilde{h} \to P[\tilde{\mathtt{n}}/\tilde{v}] \mid s_k : \tilde{h} \cdot \tilde{\mathtt{n}} \quad (\tilde{e} \downarrow \tilde{\mathtt{n}} \wedge A[\tilde{\mathtt{n}}/\tilde{v}] \downarrow \mathsf{true})$$

$$s?(\tilde{v})\{A\}; P \mid s : \tilde{\mathtt{n}} \cdot \tilde{h} \to P[\tilde{\mathtt{n}}/\tilde{v}] \mid s : \tilde{h} \quad (A[\tilde{\mathtt{n}}/\tilde{v}] \downarrow \mathsf{true})$$

$$s \rhd \{\{A_i\}l_i : P_i\}_{i \in I} \mid s : l_j \cdot \tilde{h} \to P_j \mid s : \tilde{h} \quad (j \in I \text{ and } A_j \downarrow \mathsf{true})$$

$$s \lhd \{A\}l; P \mid s : \tilde{h} \to P \mid s : \tilde{h} \cdot l \quad (A \downarrow \mathsf{true})$$

$$\mathsf{if}\ e\ \mathsf{then}\ P\ \mathsf{else}\ Q \to P \quad (e \downarrow \mathsf{true}) \qquad \mathsf{if}\ e\ \mathsf{then}\ P\ \mathsf{else}\ Q \to Q \quad (e \downarrow \mathsf{false})$$

$$\mathsf{def}\ D\ \mathsf{in}\ C[X\langle\tilde{e}\tilde{s}\rangle] \to \mathsf{def}\ D\ \mathsf{in}\ Q (\text{where } \langle X\langle\tilde{v}\tilde{s}\rangle = P\rangle \in D \text{ and } C[P[\tilde{e}/\tilde{v}]] \to Q)$$

$$s!\langle\tilde{\mathtt{n}}\rangle(\tilde{v})\{A\}; P \to \mathsf{errH} \quad (A[\tilde{\mathtt{n}}/\tilde{v}] \downarrow \mathsf{false})$$

$$s?(\tilde{v})\{A\}; P \mid s : \tilde{\mathtt{n}} \cdot \tilde{h} \to \mathsf{errT} \mid s : \tilde{h} \quad (A[\tilde{\mathtt{n}}/\tilde{v}] \downarrow \mathsf{false})$$

$$s \rhd \{\{A_i\}l_i : P_i\}_{i \in I} \mid s : l_j \cdot \tilde{h} \to \mathsf{errT} \mid s : \tilde{h} \quad (j \in I \text{ and } A_j \downarrow \mathsf{false})$$

$$s \lhd \{A\}l; P \to \mathsf{errH} \quad (A \downarrow \mathsf{false})$$

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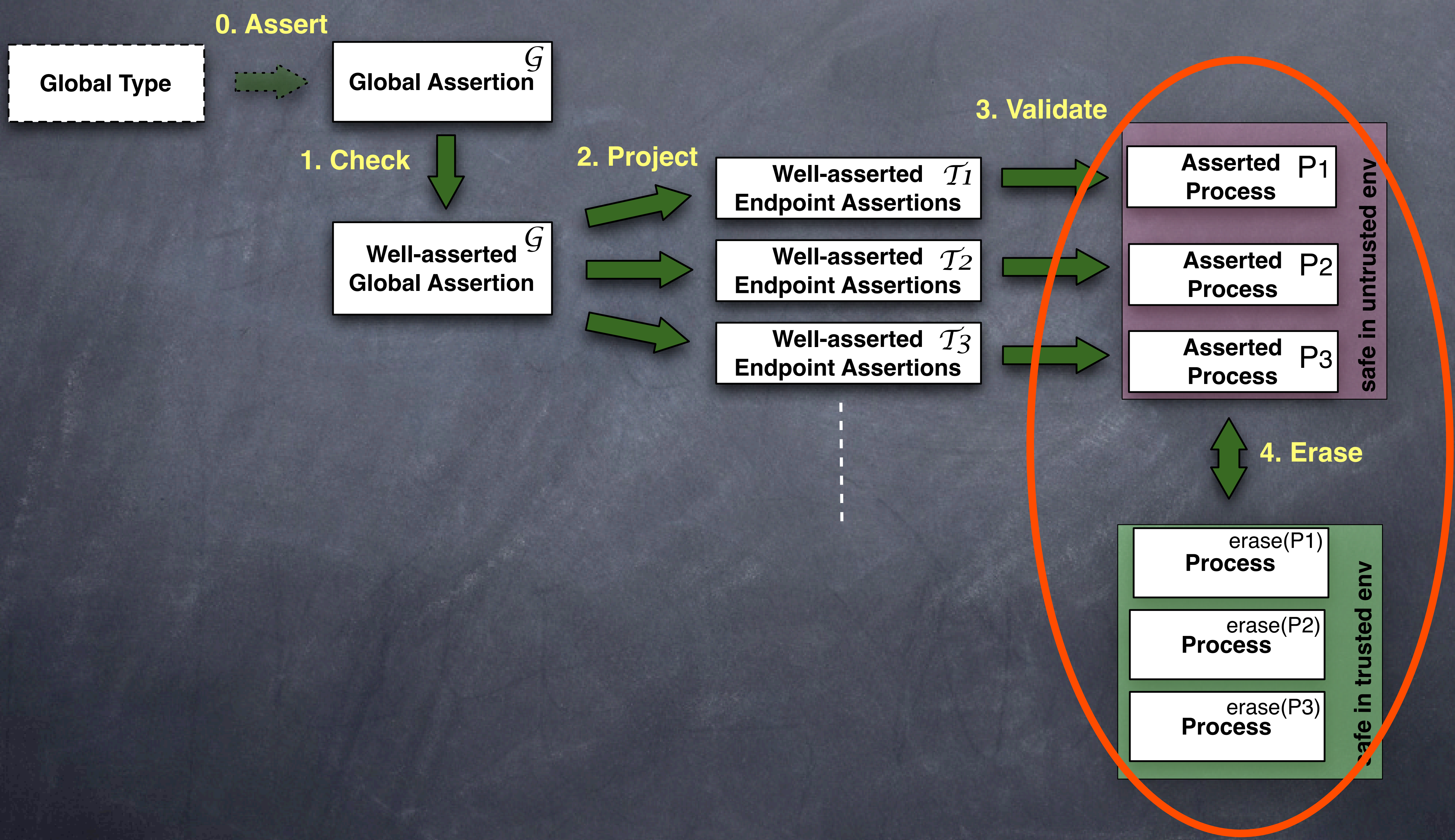

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Validating asserted processes

$$\mathcal{C};\Gamma \vdash P \triangleright \Delta$$

under the assertion environment C and the sorting Γ, P is validated w.r.t. the assertion assignment Δ

$$\frac{\mathcal{C} \supset A[\tilde{e}/\tilde{v}] \quad \mathcal{C};\Gamma \vdash P[\tilde{e}/\tilde{v}] \triangleright \Delta, \tilde{s} : \mathcal{T}[\tilde{e}/\tilde{v}] \,@\, \mathtt{p}}{\mathcal{C};\Gamma \vdash s_k!\langle\tilde{e}\rangle(\tilde{v})\{A\}; P \triangleright \Delta, \tilde{s} : k!(\tilde{v} : \tilde{S})\{A\}; \mathcal{T} \,@\, \mathtt{p}}$$

$$\frac{\mathcal{C} \wedge A_i, \Gamma \vdash P_i \triangleright \Delta, \tilde{s} : \mathcal{T}_i \,@\, \mathtt{p} \quad \forall i \in I}{\mathcal{C};\Gamma \vdash \ s_k \rhd \{\{A_i\}l_i : P_i\}_{i\in I} \triangleright \Delta, \tilde{s} : k\&\{\{A_i\}l_i : \mathcal{T}_i\}_{i\in I} \,@\, \mathtt{p}}$$

Main Results

- Validated processes can be “simulated” by their end-point assertions
- End-point assertions do not yield errors (by construction)
- A validated process never reaches errors
- Validation is decidable

Main results 2

- In a trusted environment, all assertions of validate processes can be turned into true
- A monitor can be automatically deduced from validated processes (it has to check sent/selection messages)
- In an untrusted environment, the monitor may guard processes and help in debugging

Future work

- Study properties of suitable logics for global assertions
  - tractability/decidability
  - complexity
- Play with implementations
- Apply this context to financial protocols

Thank you…