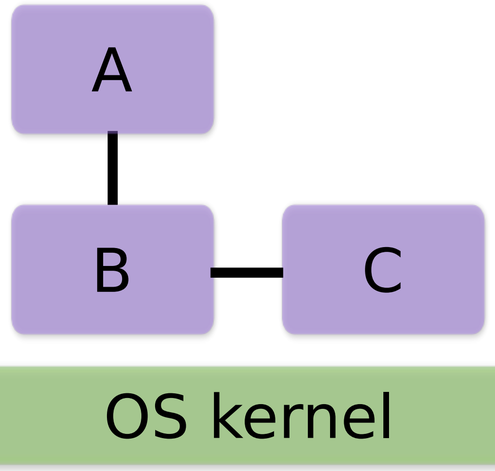
Automated Verification of RPC Stub Code

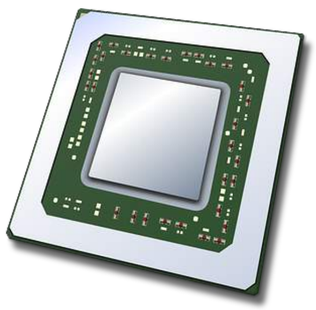
Matthew Fernandez, June Andronick, Gerwin Klein, Ihor Kuz

FM, June 2015

High Assurance Component-based Software

NICTA





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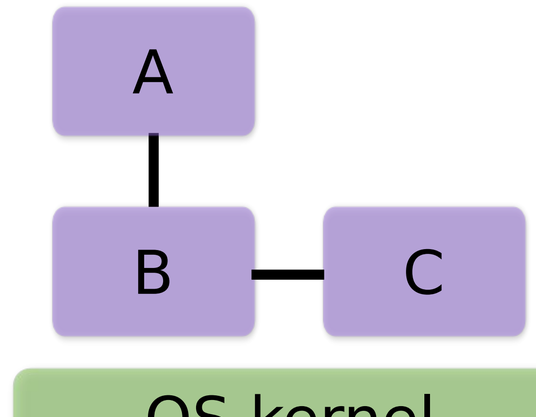
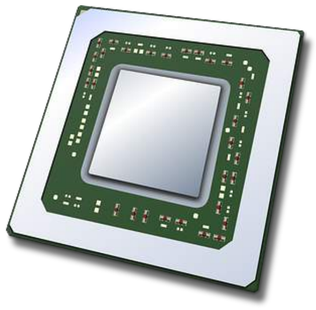


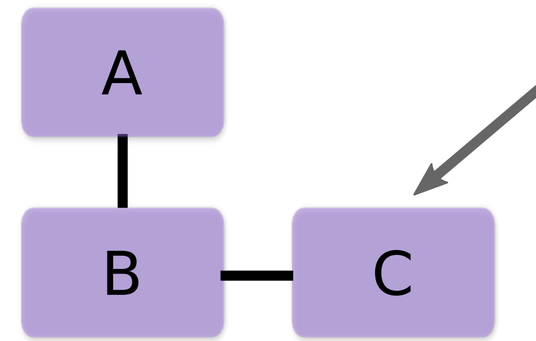


seL4

- 10,000 LoC microkernel
- functional correctness proof
- strong isolation properties
- fast and predictable

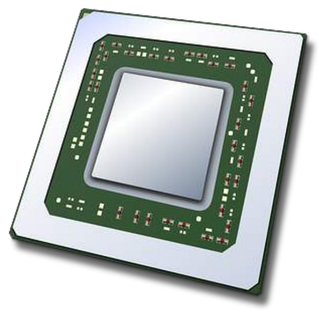
High Assurance Component-based Software

NICTA



components

- functionality
- policy
- >1 MLoC
- varied correctness criteria



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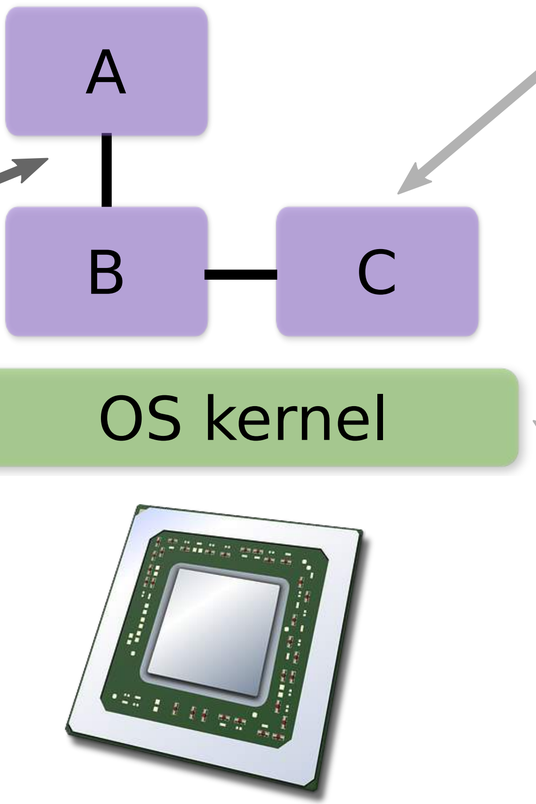

components

- functionality
- policy
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- varied correctness criteria

CAmkES

- static component platform
- formal architectural model
- optimised for seL4
- designed for verification

seL4

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- functional correctness proof
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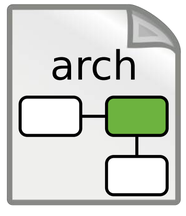
- fast and predictable

Component Compilation



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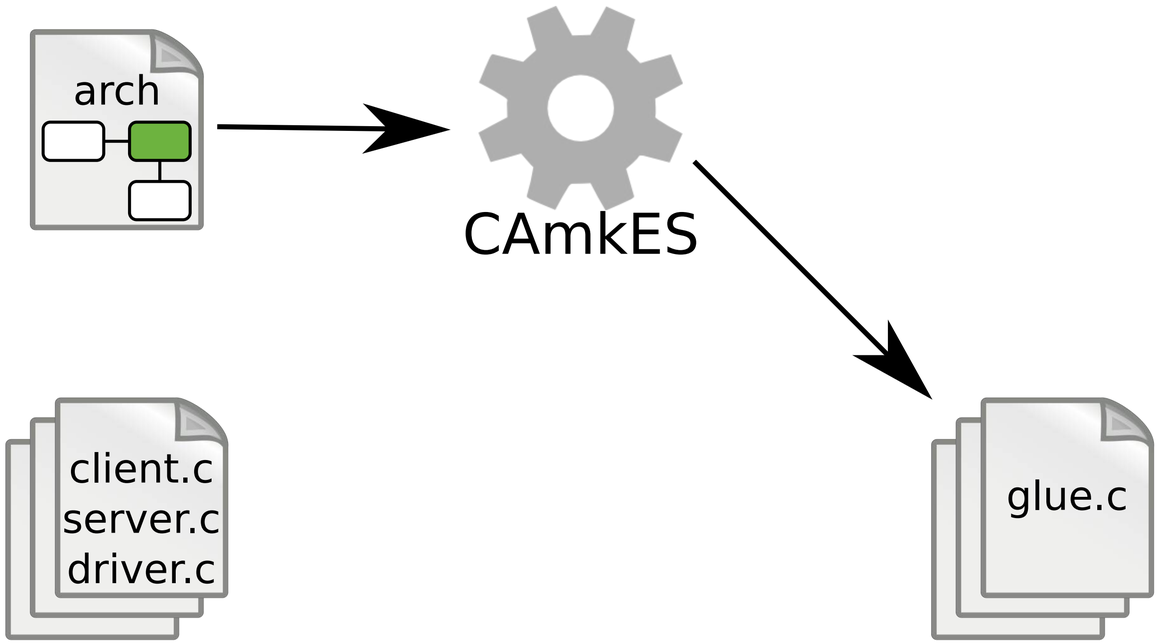

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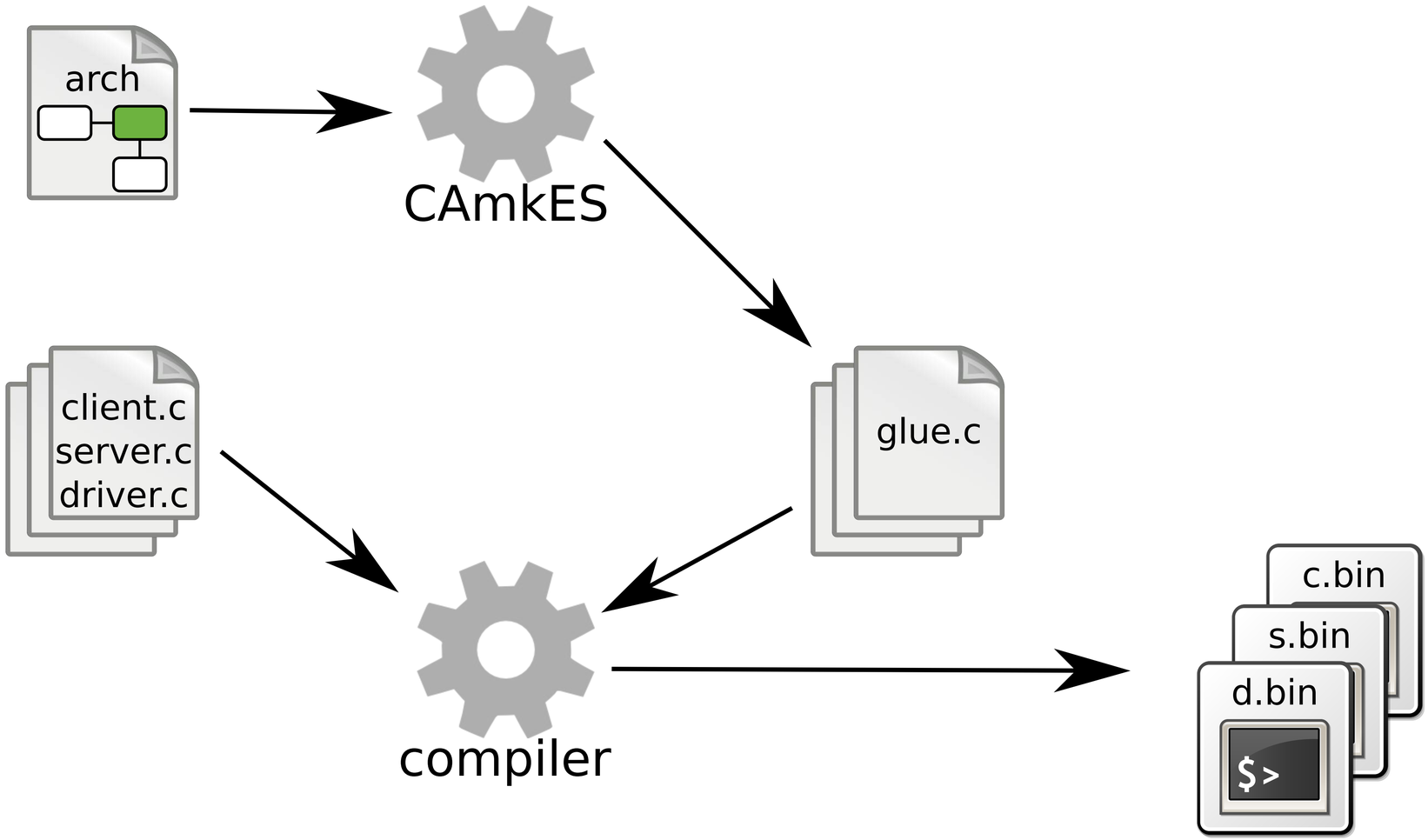

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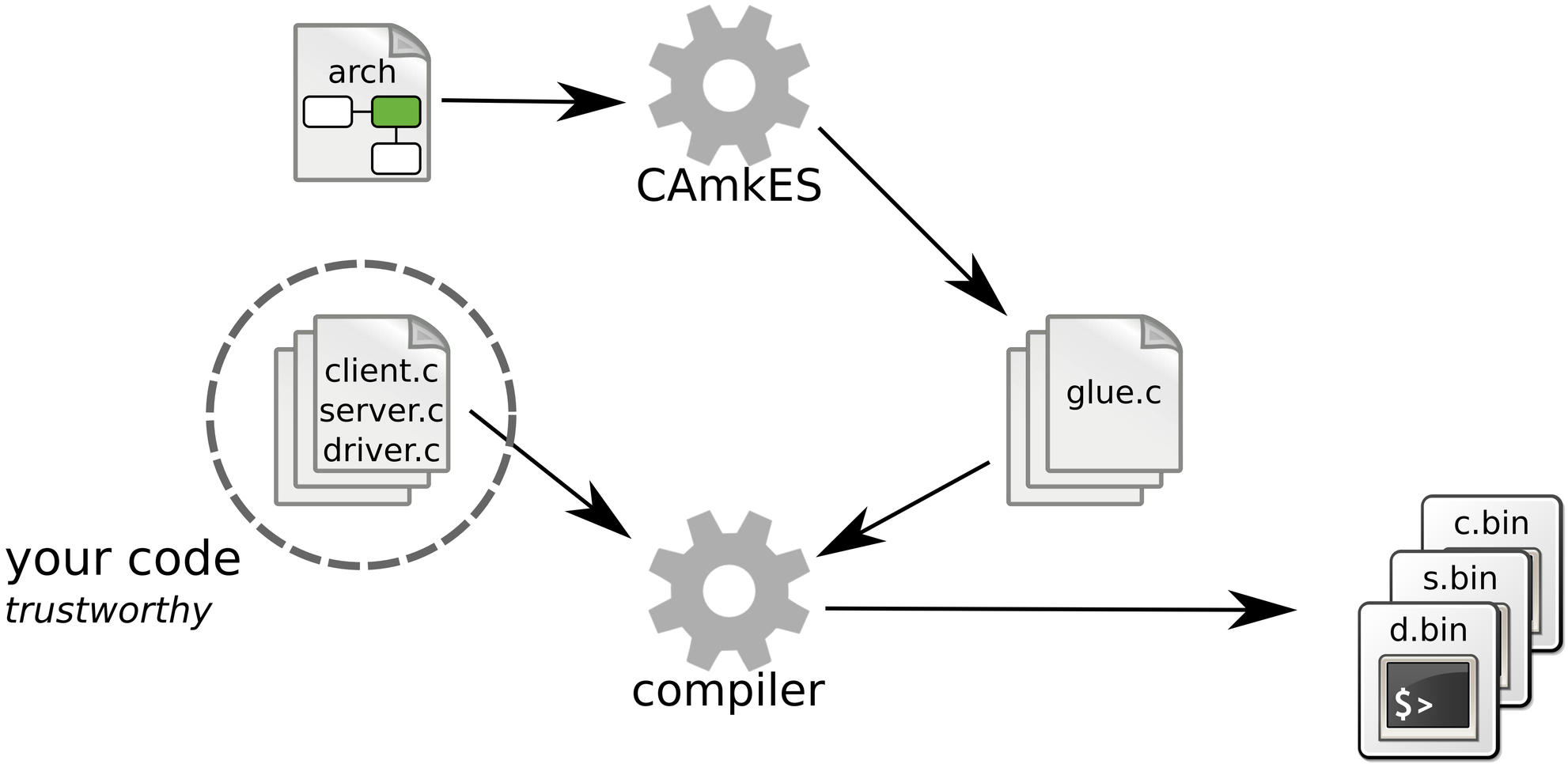

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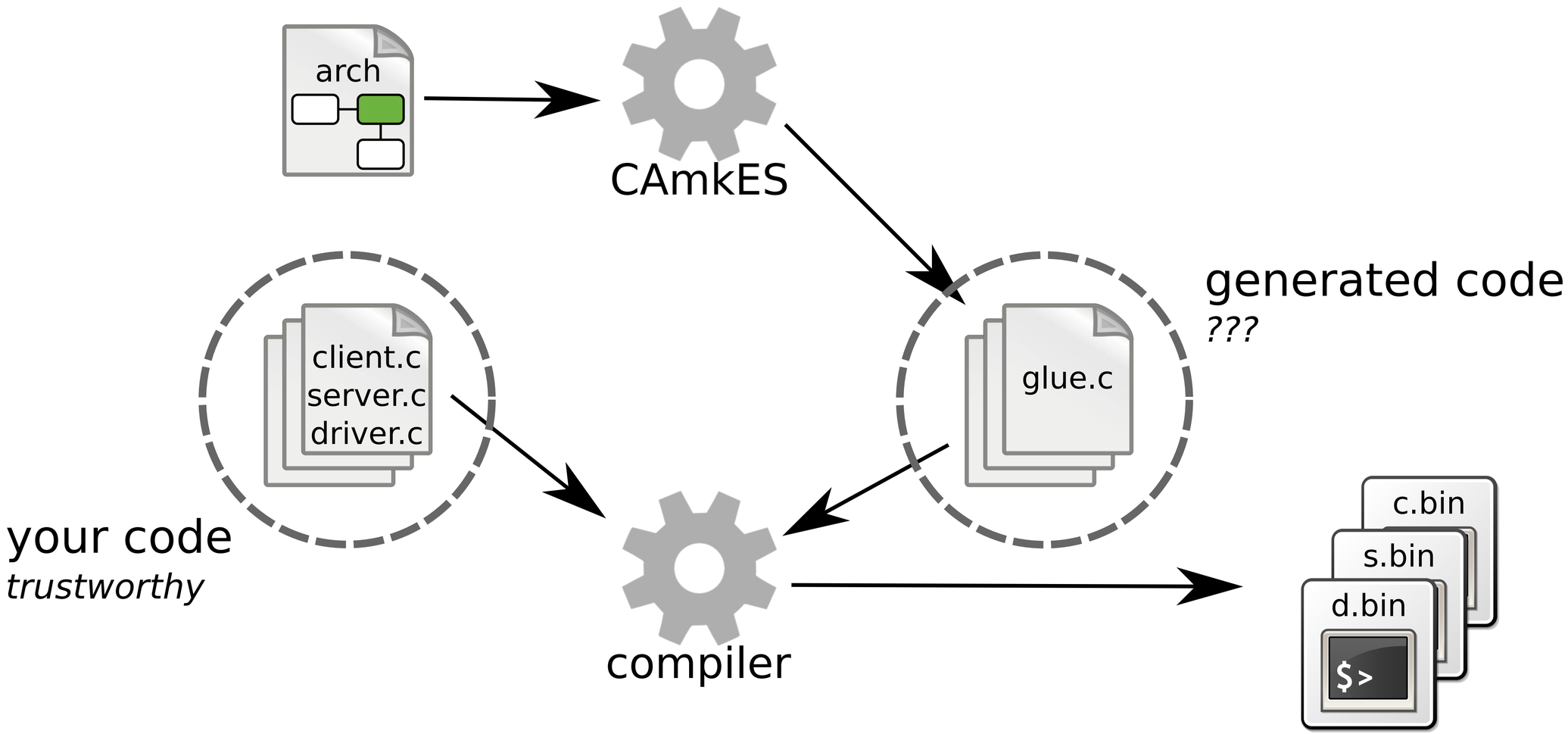

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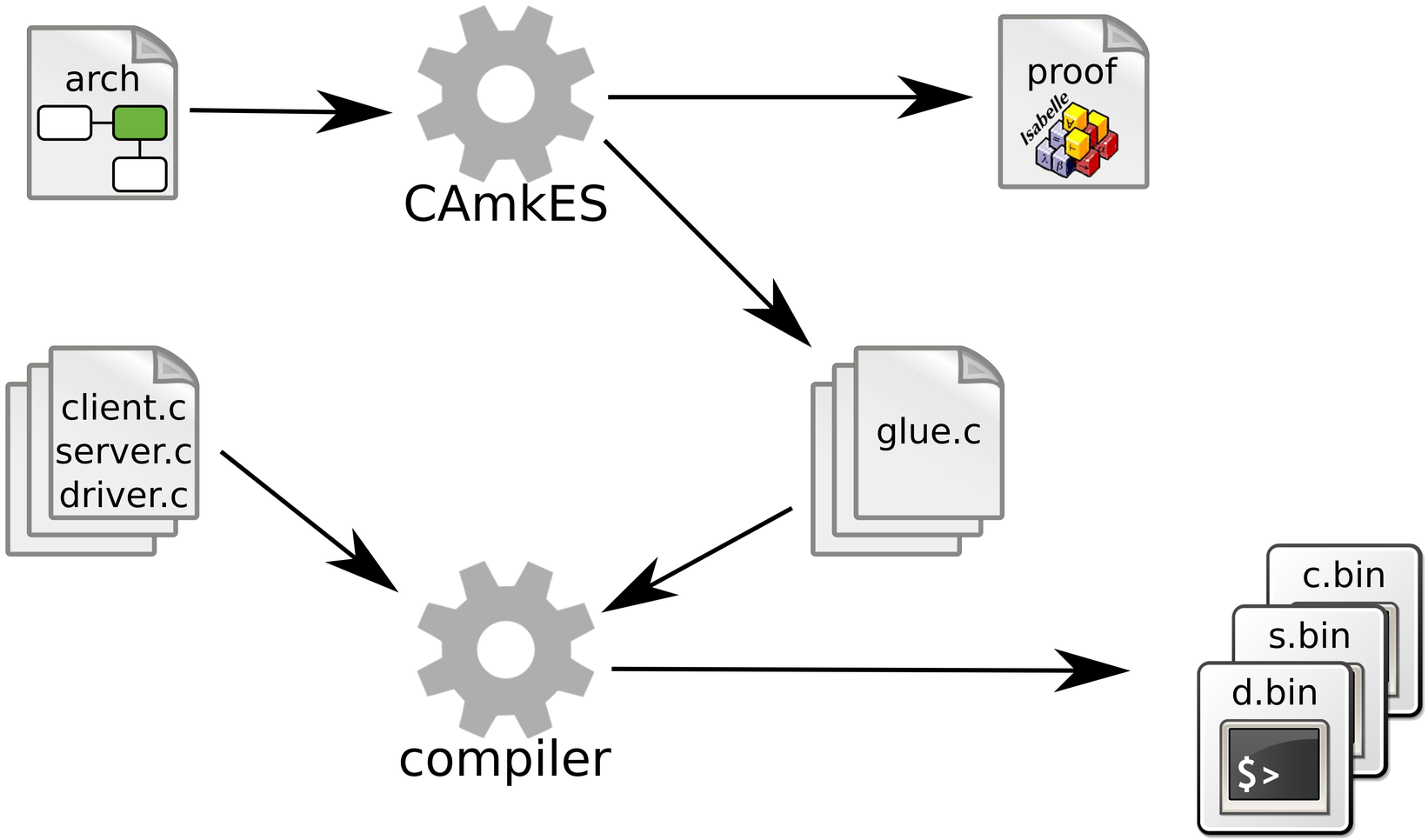

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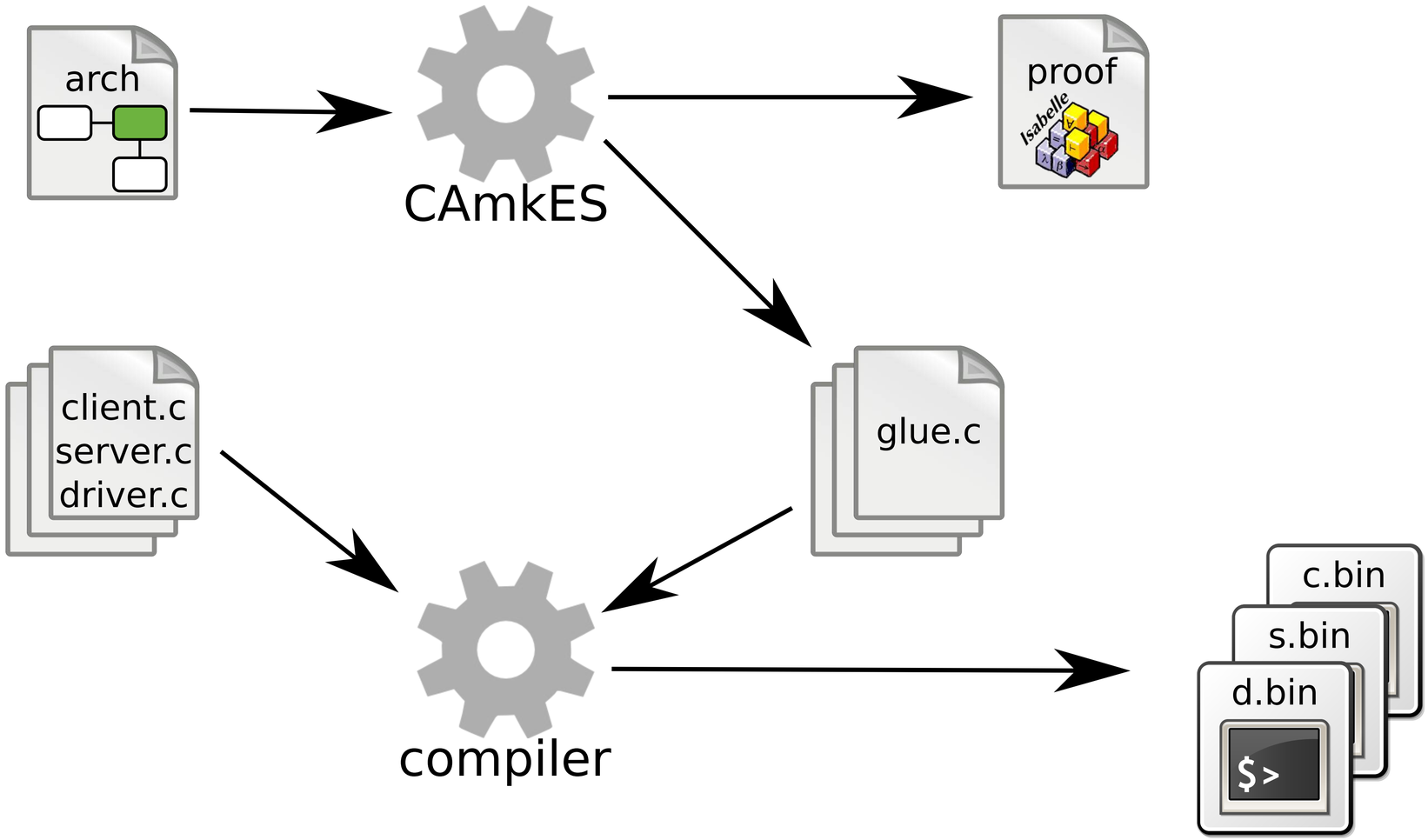

generated proofs for generated code

Challenges

NICTA

What is correctness?

How do we prove it?

How do we automate it?

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Generated Code

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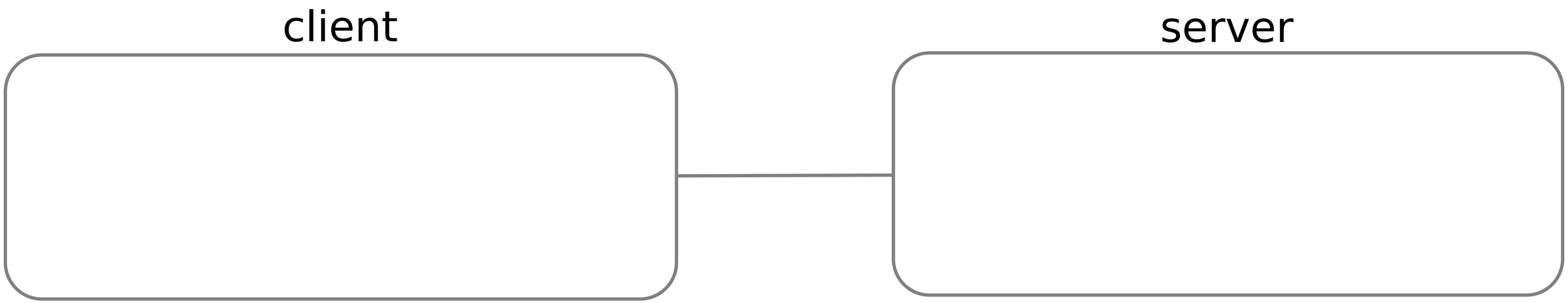

Generated Code

NICTA

client

```
void run() {
  int x = 2;
  int y = 3;
  int z = c_max(x, y);
  printf("max(%d, %d) = %d\n", x, y, z);
}
```

server

```
int s_max(int a, int b) {
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seL4

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```c
int c_max(int p, int q) {
  c_marshal(p, q);
  seL4_Call(...);
  int r = c_unmarshal();
  return r;
}
```

seL4

```c
void handle_rpc() {
  seL4_Wait(...);
  s_unmarshal(&i, &j);
  int k = s_max(i, j);
  s_marshal(k);
  seL4_Reply(...);
}
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Generated Code

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seL4

{[**P**]}

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{[**Q**]}

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Generated Code

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{[Q]}

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RPC invocation ≅ local invocation

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NICTA

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NICTA

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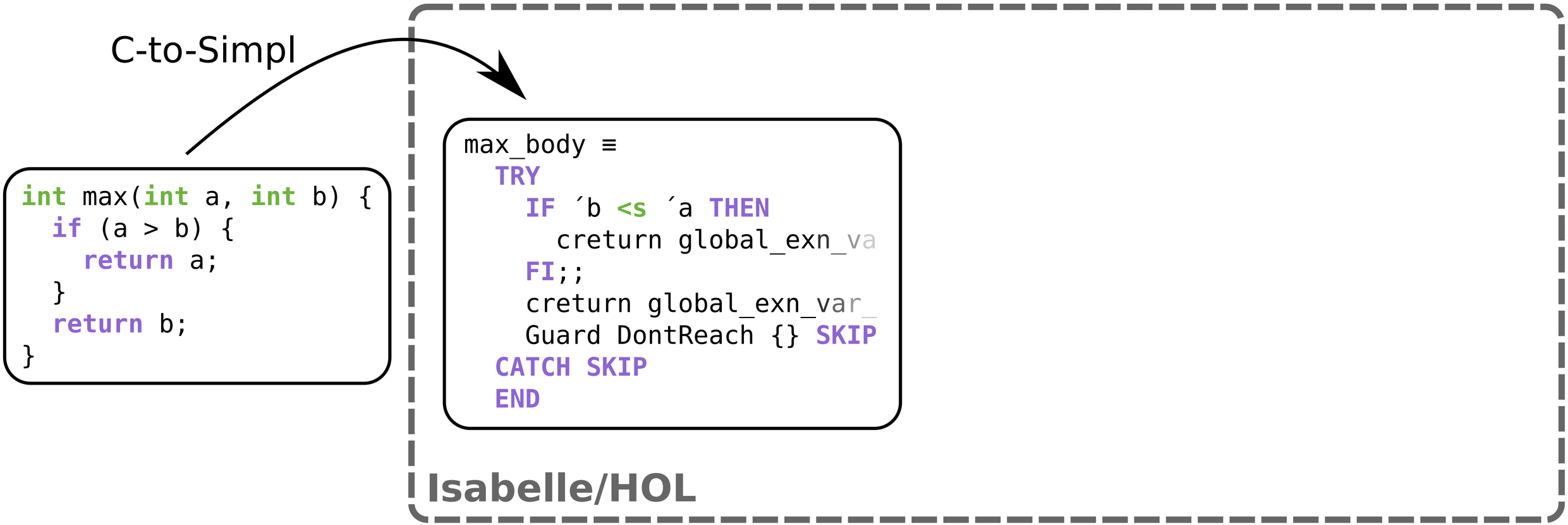
NICTA

- **Isabelle/HOL** — LCF-style interactive theorem prover
- **C-to-Simpl Parser** — Semantics-preserving translation of C to Simpl



Toolchain (prior work)

- **Isabelle/HOL** — LCF-style interactive theorem prover
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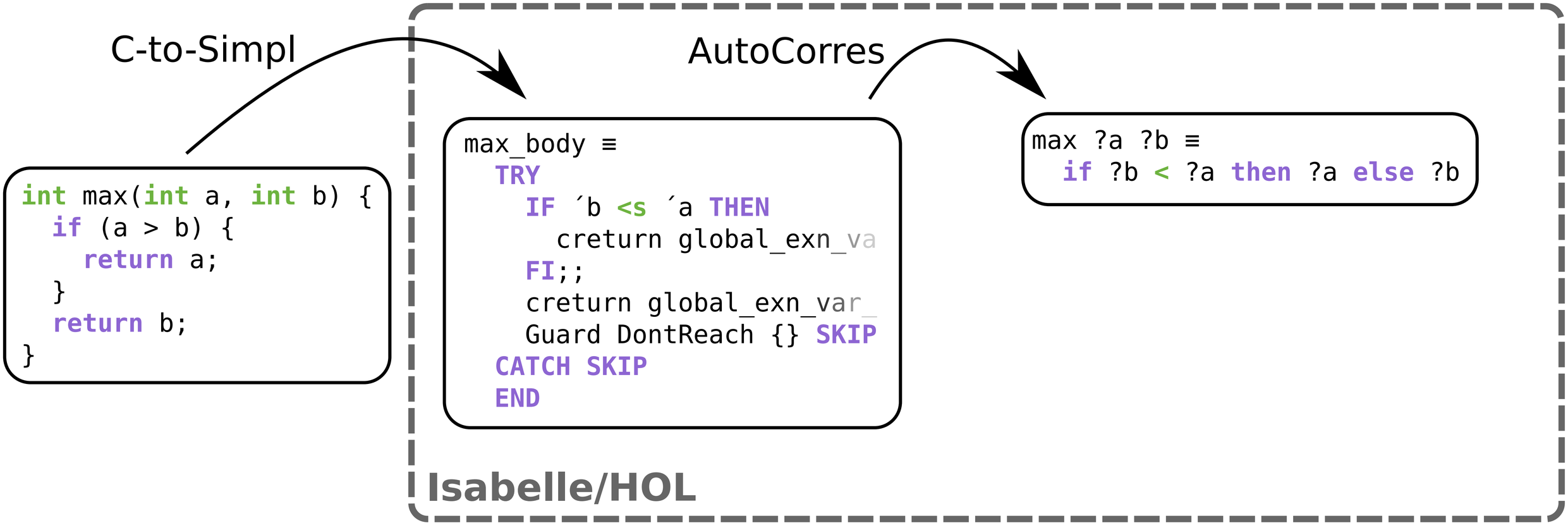
- **AutoCorres** — Verified abstraction of Simpl



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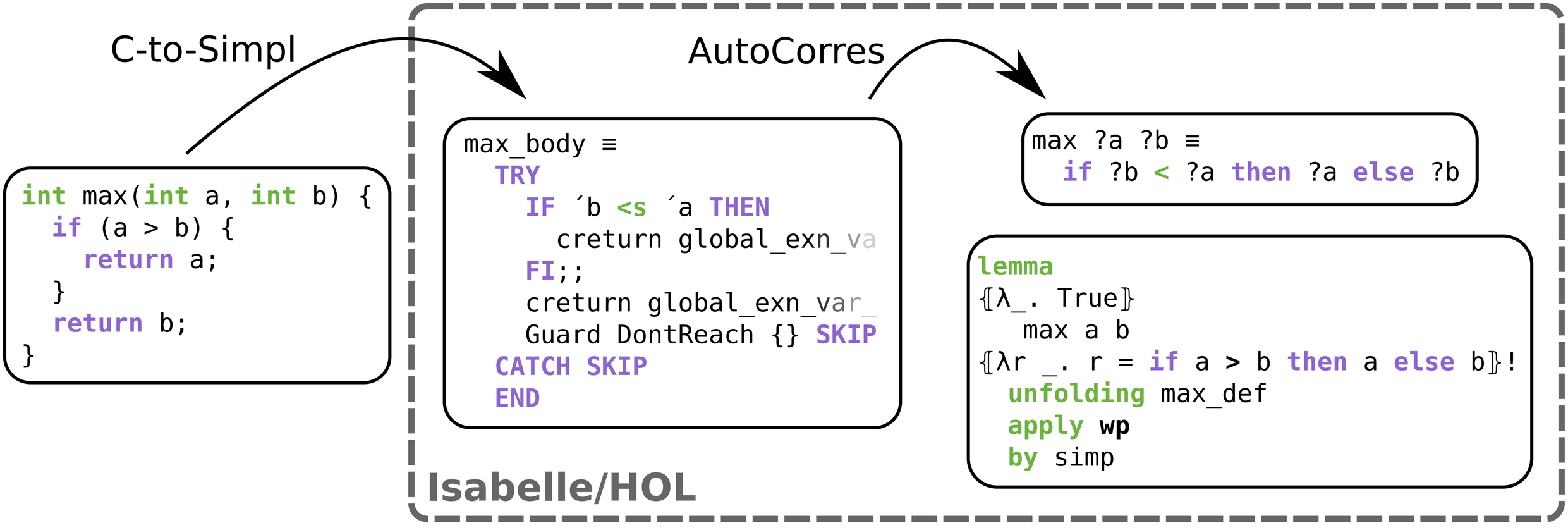

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NICTA

- **Isabelle/HOL** — LCF-style interactive theorem prover
- **C-to-Simpl Parser** — Semantics-preserving translation of C to Simpl
- **AutoCorres** — Verified abstraction of Simpl
- **WP** — weakest-precondition reasoning for Hoare triples

C-to-Simpl

```
int max(int a, int b) {
  if (a > b) {
    return a;
  }
  return b;
}
```

AutoCorres

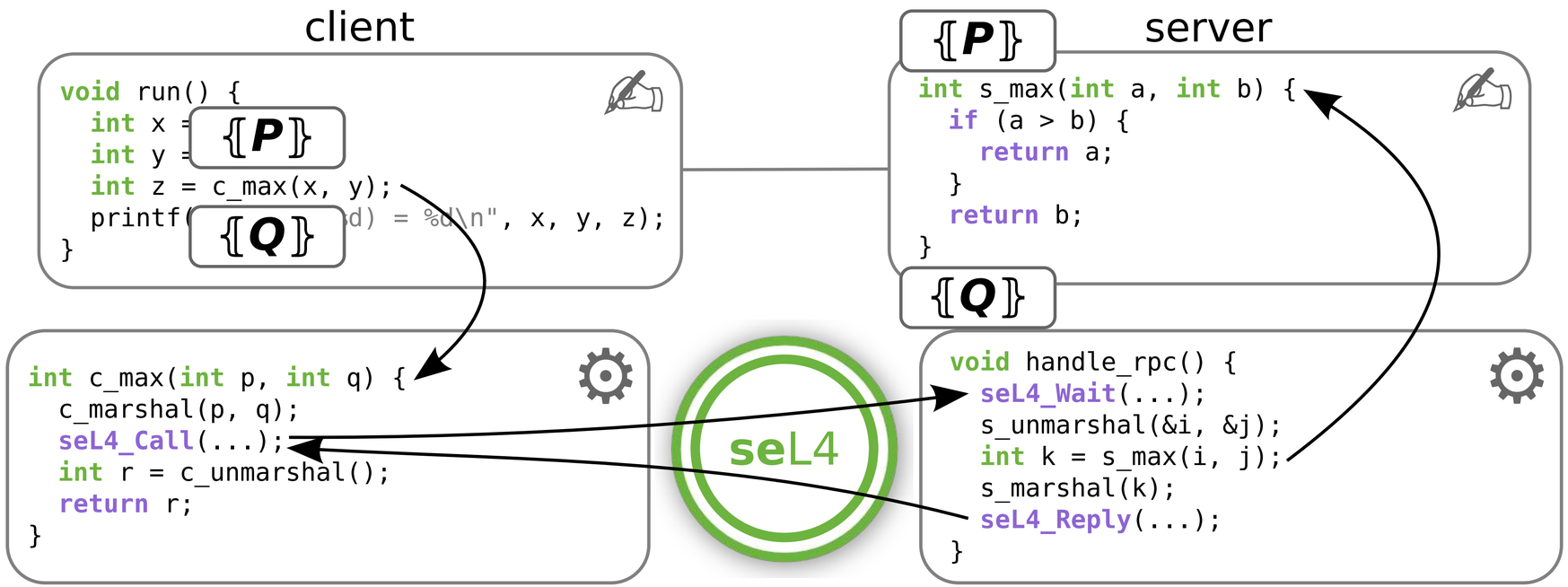
```
max_body ≡
  TRY
    IF ´b <s ´a THEN
      creturn global_exn_va
    FI;;
    creturn global_exn_var_
    Guard DontReach {} SKIP
  CATCH SKIP
  END
```

```
max ?a ?b ≡
  if ?b < ?a then ?a else ?b
```

```
lemma
⦇λ_. True⦈
   max a b
⦇λr _. r = if a > b then a else b⦈!
  unfolding max_def
  apply wp
  by simp
```

Isabelle/HOL

Verifying Generated Code



RPC invocation ≅ local invocation

Verifying Generated Code

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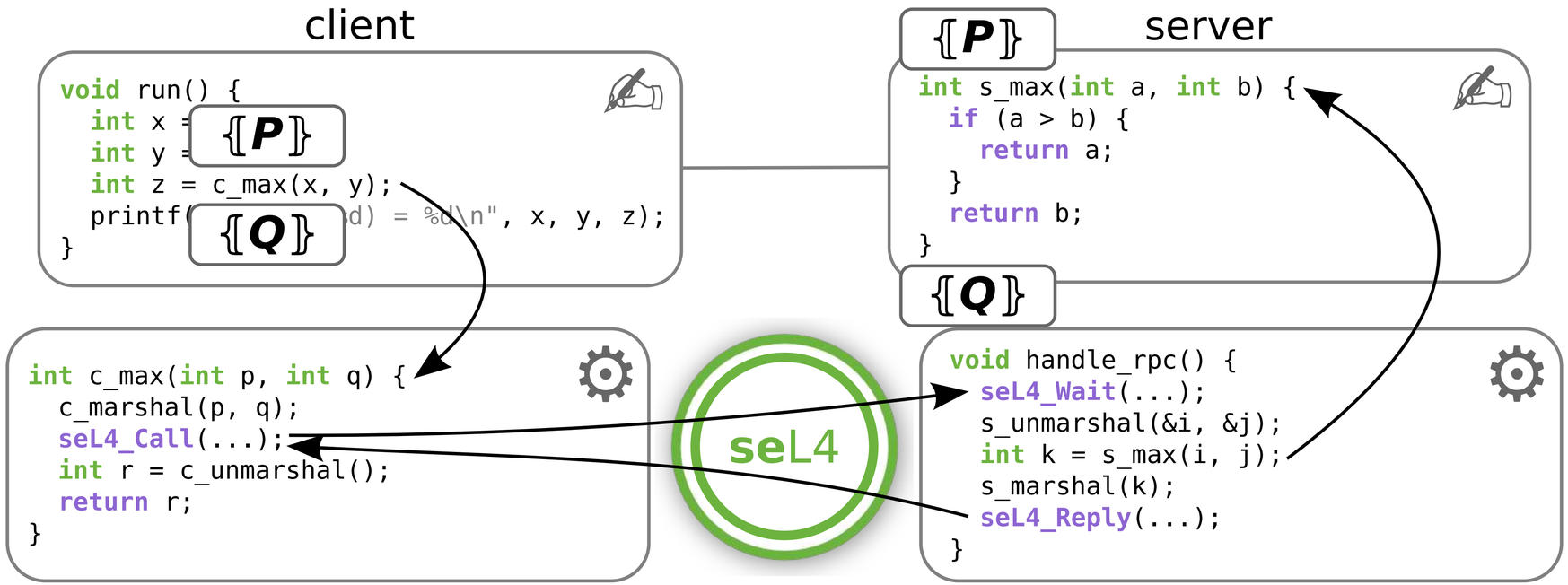
$$\{\!|P|\!\}\ s\_max\ a\ b\ \{\!|Q|\!\}! \quad \Rightarrow \quad \{\!|P|\!\}\ c\_max\ a\ b\ \{\!|Q|\!\}!$$



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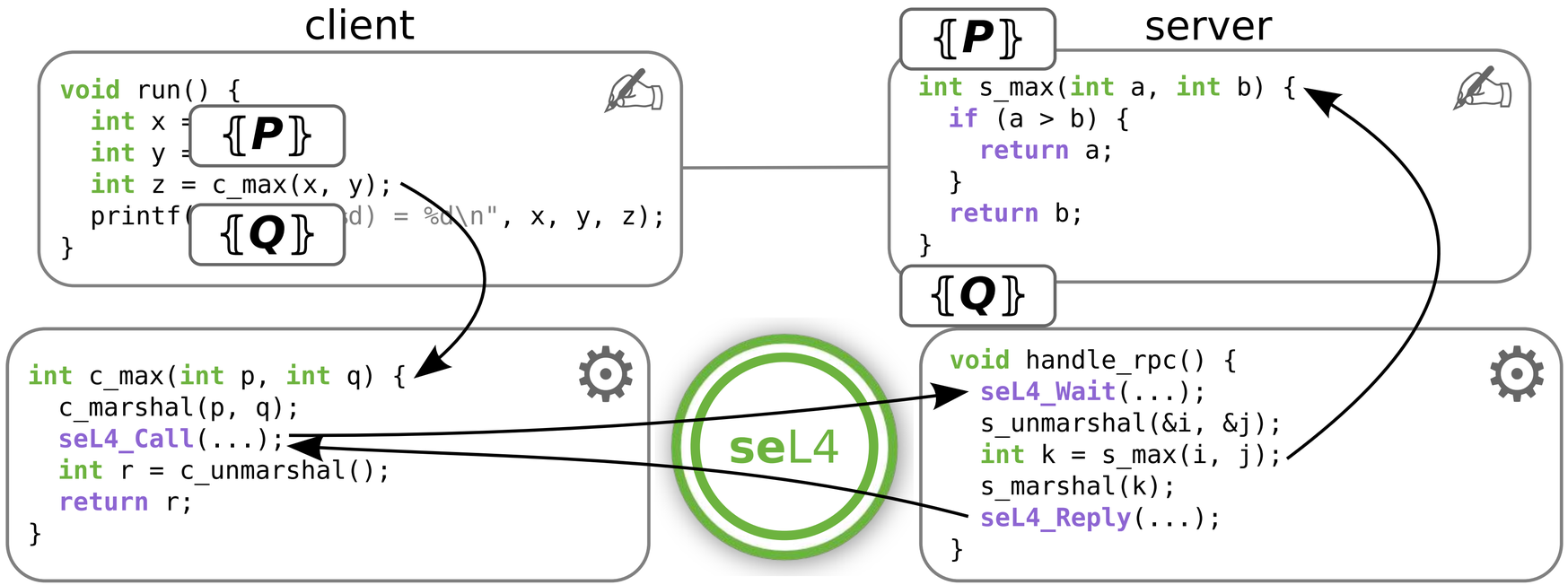
$$\{\!|P|\!\}\ s\_max\ a\ b\ \{\!|Q|\!\}! \quad \Rightarrow \quad \{\!|P|\!\}\ \textbf{do}\ c\_marshall\ a\ b;\ seL4\_Call\ ...;\ c\_unmarshal\ r\ \textbf{od}\ \{\!|Q|\!\}!$$



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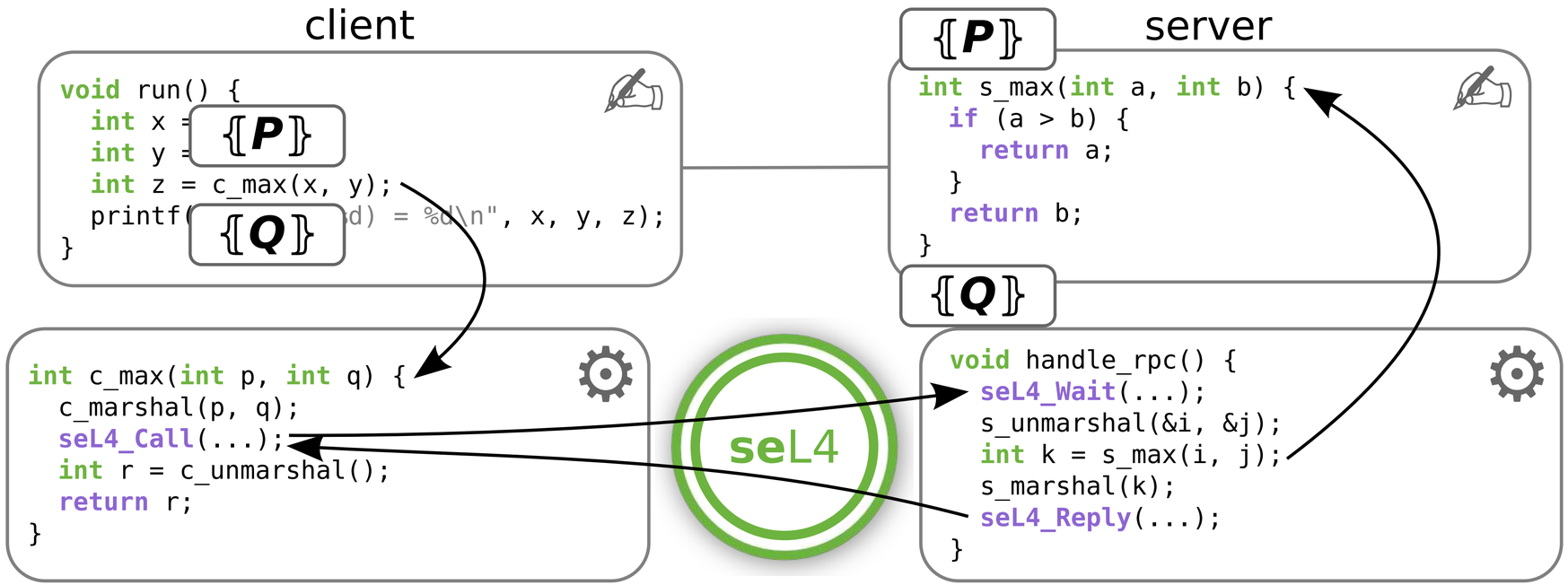
$$\{\!|P|\!\}\ s\_max\ a\ b\ \{\!|Q|\!\}! \quad \Rightarrow \quad \{\!|P|\!\}$$

```
do c_marshall a b;
   s_unmarshal a b;
   r ← s_max a b;
   s_marshal r;
   c_unmarshal r
od
```

$\{\!|Q|\!\}!$



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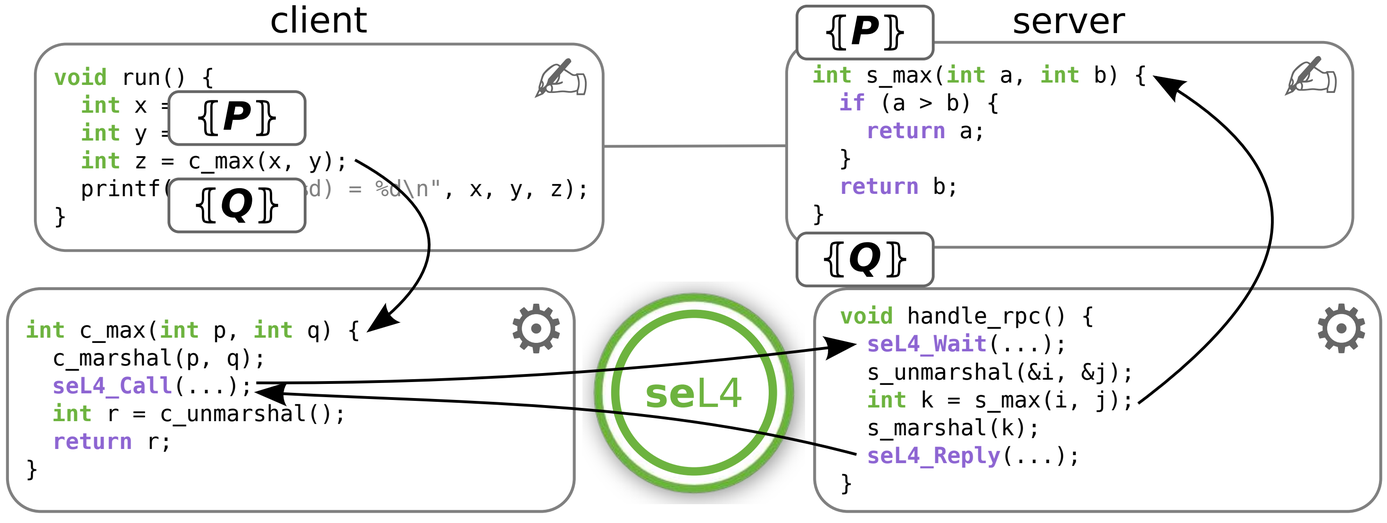

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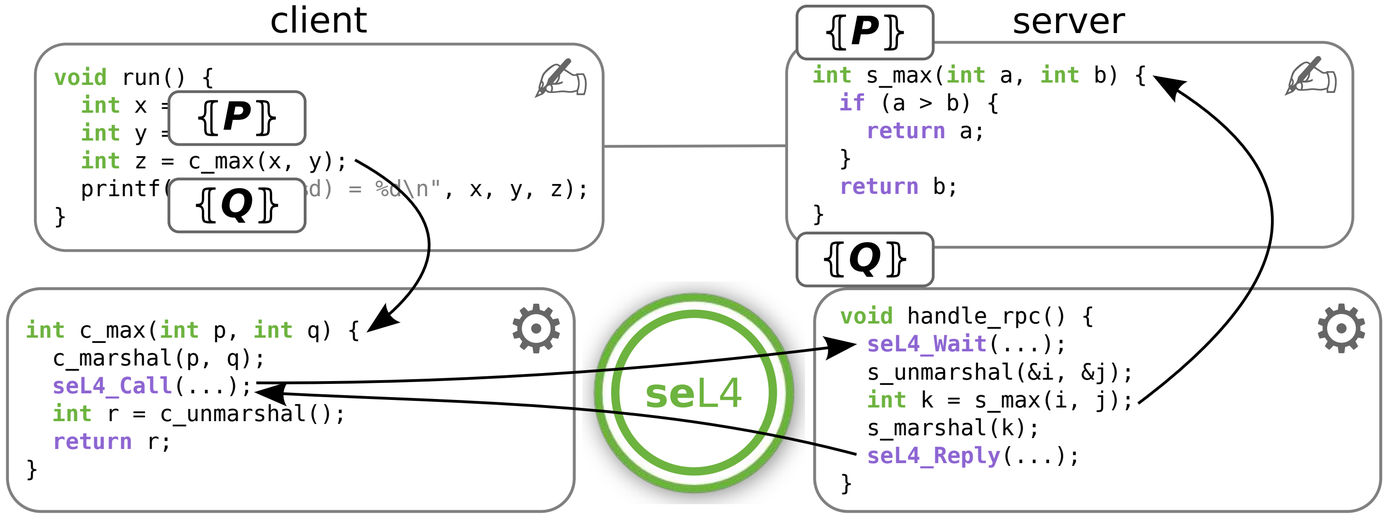
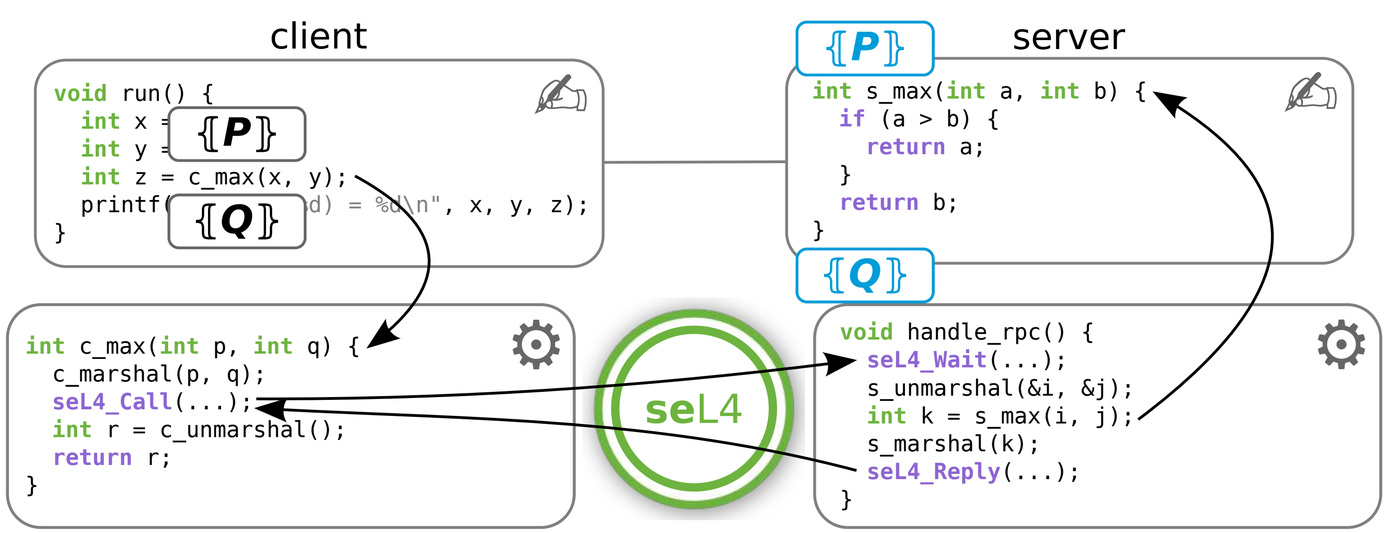
locale rpcstubs$_{max}$ =



Generated Proofs

locale rpcstubs$_{max}$ =
  fixes P_{max} :: *lifted_globals ⇒ int ⇒ int ⇒ bool*
  fixes Q_{max} :: *lifted_globals ⇒ lifted_globals ⇒ int ⇒ int ⇒ int ⇒ bool*
  assumes
    ⦃λs. P_{max} *s a b⦄*
      s_max a b
    ⦃λr s. Q_{max} *s0 s r a b⦄!*



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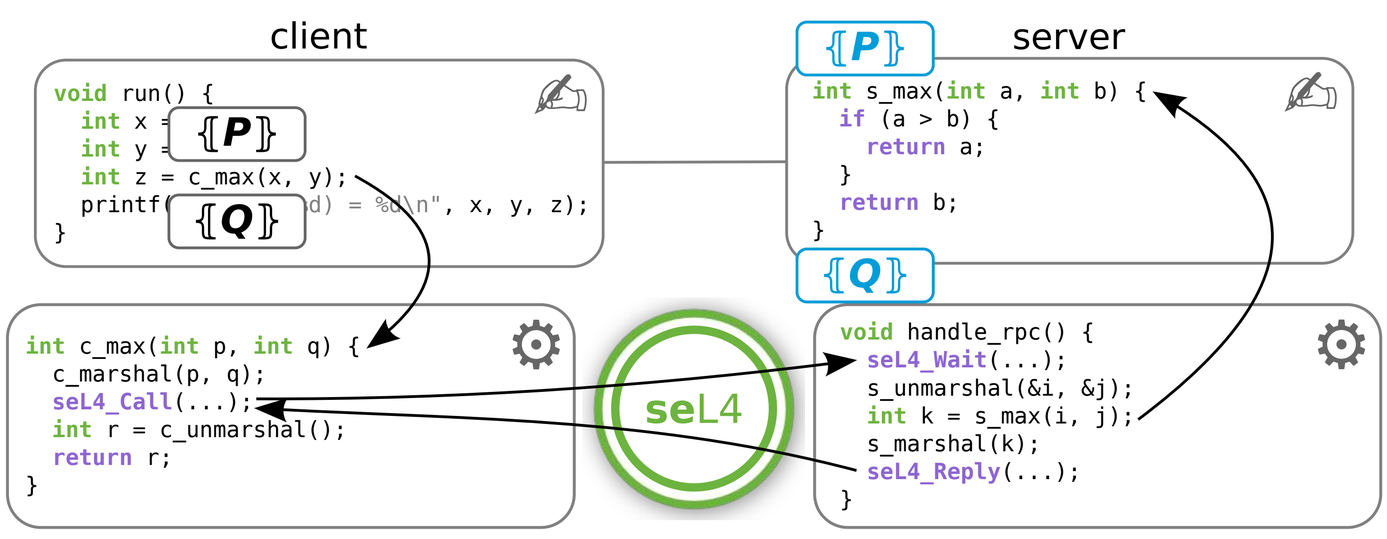

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theorem

{

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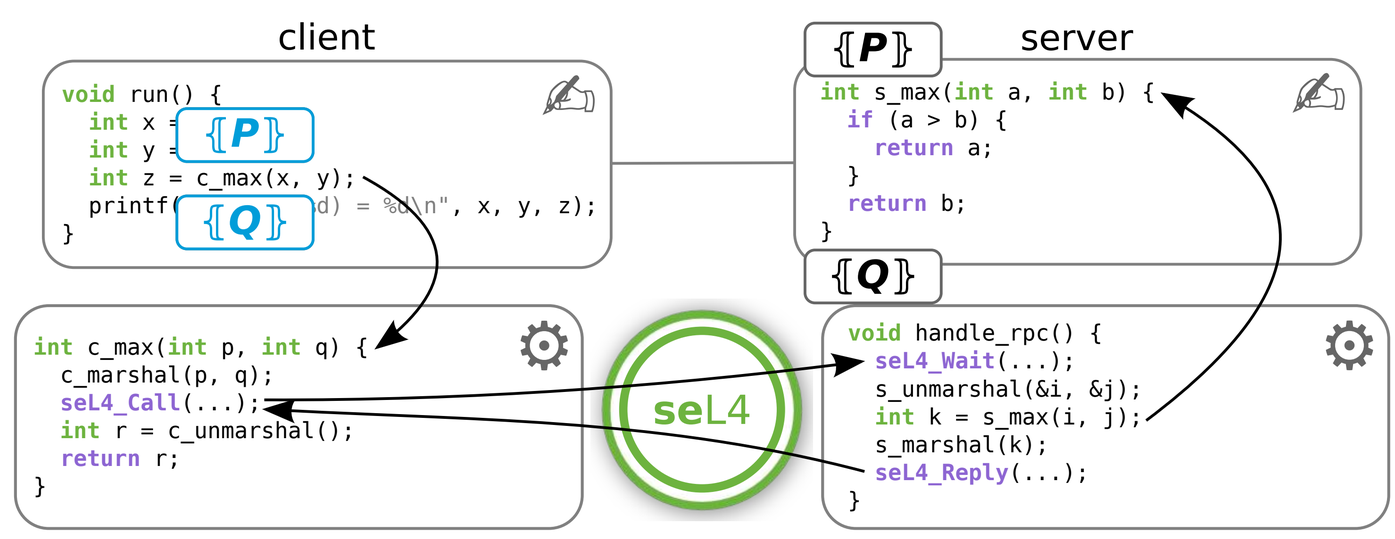

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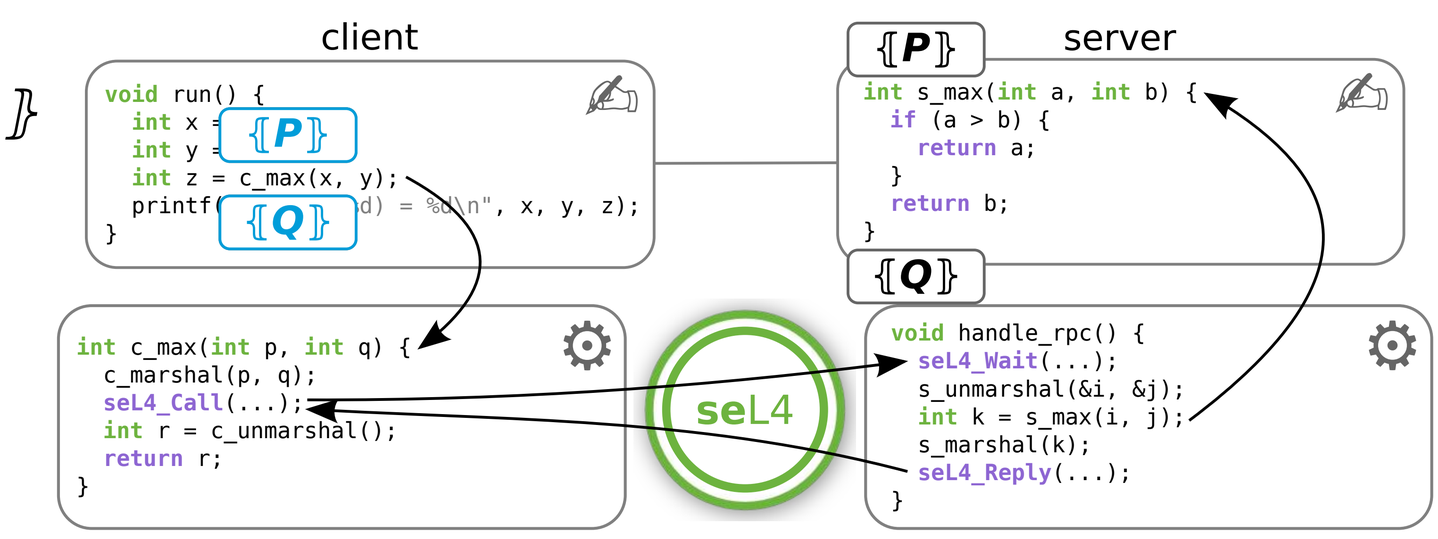
theorem
  {
    do *c_marshal a b;*
      s_unmarshal a b;
      r ← s_max a b;
      s_marshal r;
      c_unmarshal r
    od
  {

}

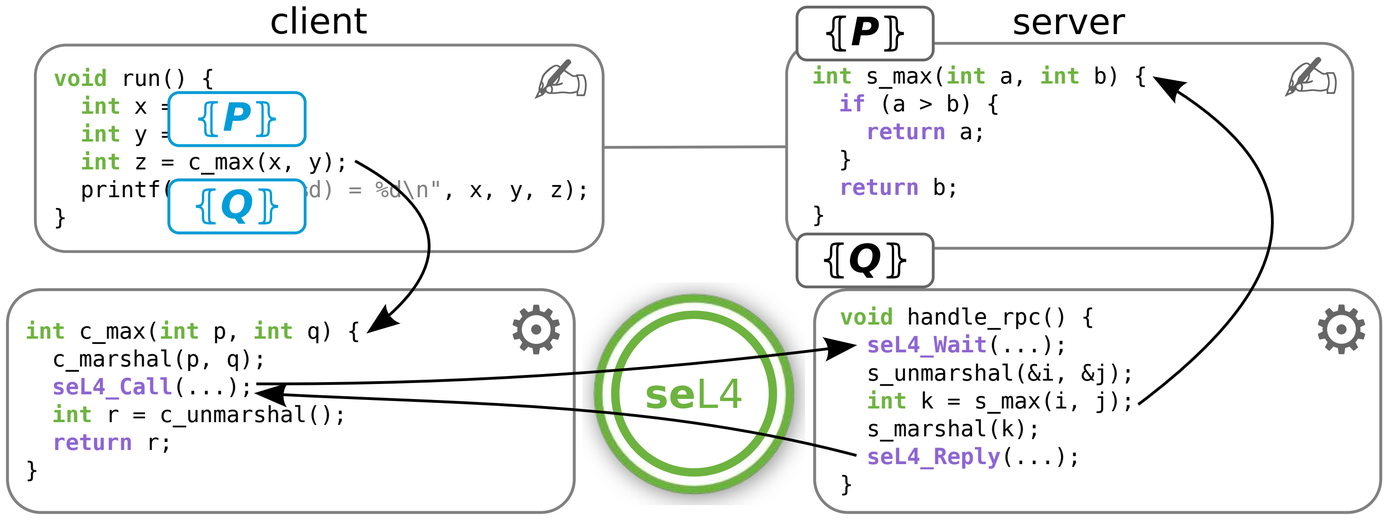


}!

Generated Proofs

locale rpcstubs$_{max}$ =
  fixes P_{max} :: *lifted_globals ⇒ int ⇒ int ⇒ bool*
  fixes Q_{max} :: *lifted_globals ⇒ lifted_globals ⇒ int ⇒ int ⇒ int ⇒ bool*
  assumes
    ⦃λs. s = s0 ∧ inv s ∧ P_{max} s a b⦄
      s_max a b
    ⦃λr s. inv s ∧ Q_{max} s0 s r a b⦄!

theorem
⦃λs. s = s0 ∧ inv s ∧ P_{max} s a b⦄
  do *c_marshal a b;*
    s_unmarshal a b;
    r ← s_max a b;
    s_marshal r;
    c_unmarshal r
  od
⦃λr s. inv s ∧ Q_{max} s0 s r a b⦄!



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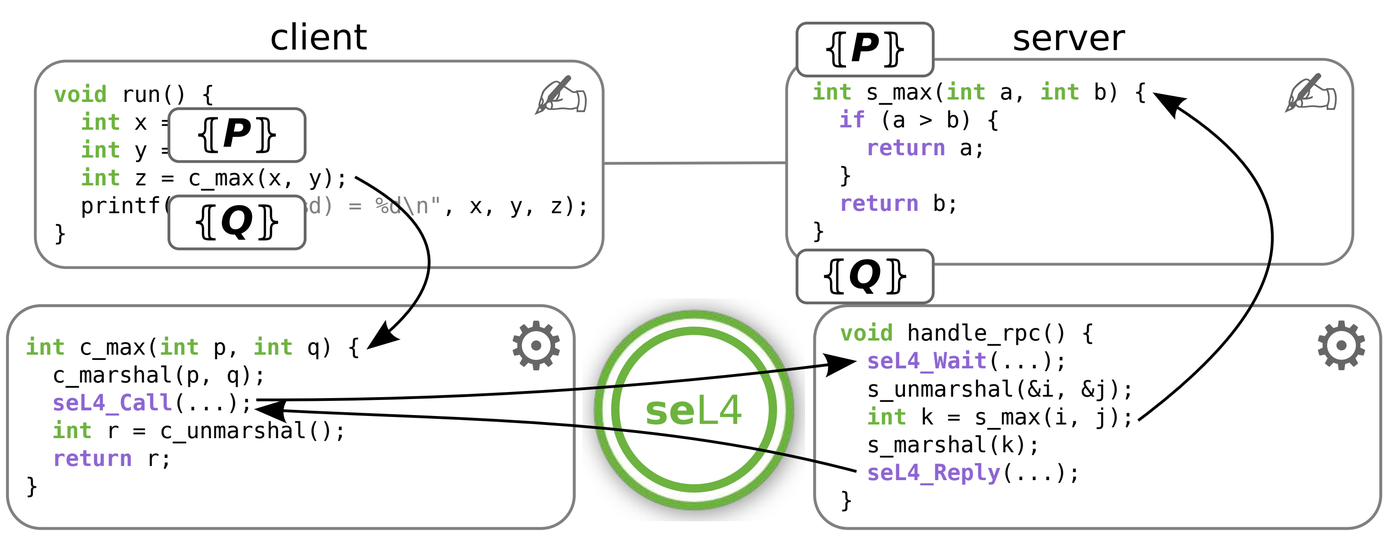
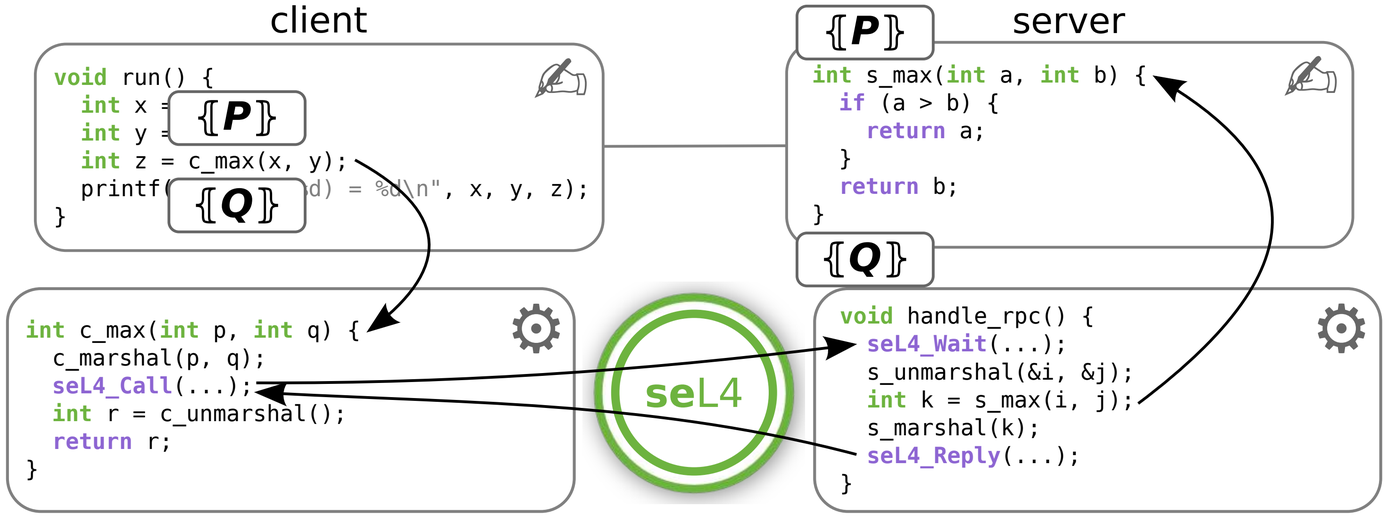


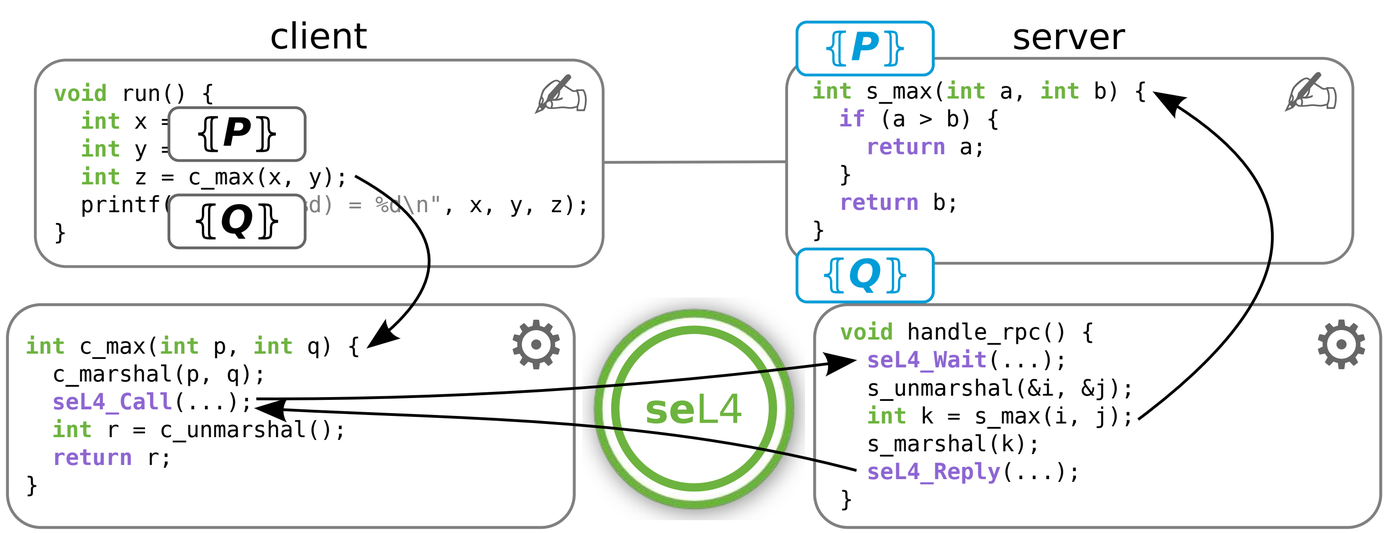
Composing Proofs



Composing Proofs

theorem

$$\{\!|\lambda\_.\ True|\!\}$$
$$\quad s\_max\ a\ b$$
$$\{\!|\lambda r\ \_.\ r = \textbf{if}\ a > b\ \textbf{then}\ a\ \textbf{else}\ b|\!\}!$$



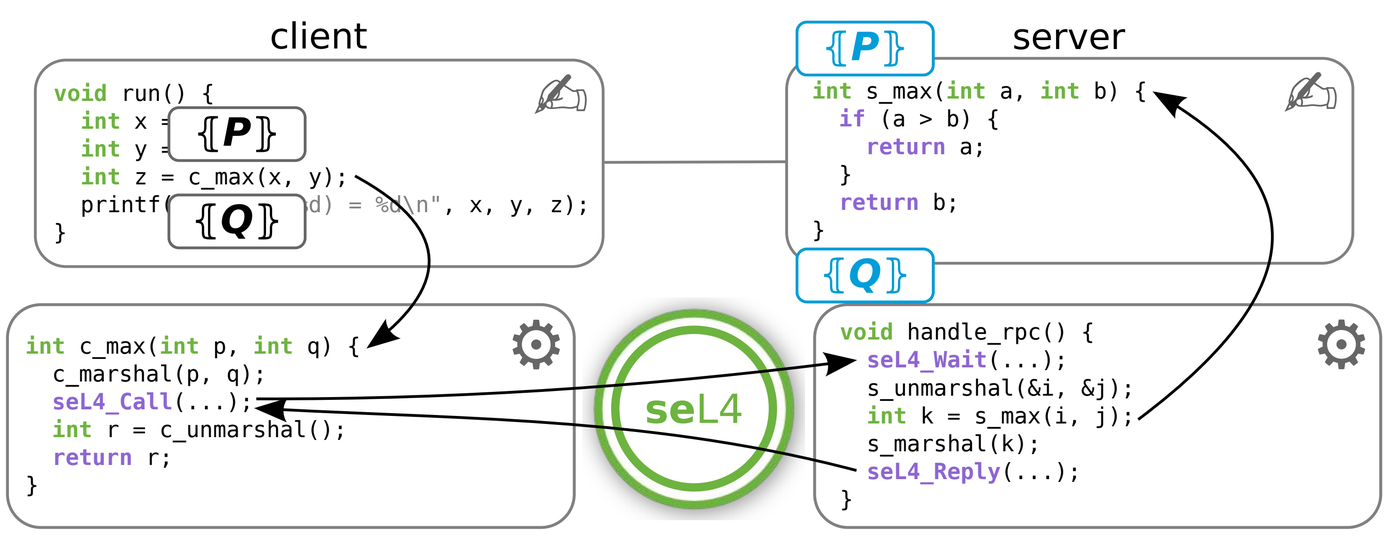
Composing Proofs

theorem

{⟦λ_. True⟧}
* s_max a b*
*{⟦λr _. r = **if** a > b **then** a **else** b⟧}!*

interpretation $rpcstubs_{max}$

λ_ _ _. True -- P_{max}
*λ_ _ r a b. r = **if** a > b **then** a **else** b* -- Q_{max}



Composing Proofs

NICTA

theorem

$\{\!|\lambda\_.\ True|\!\}$
  s_max a b
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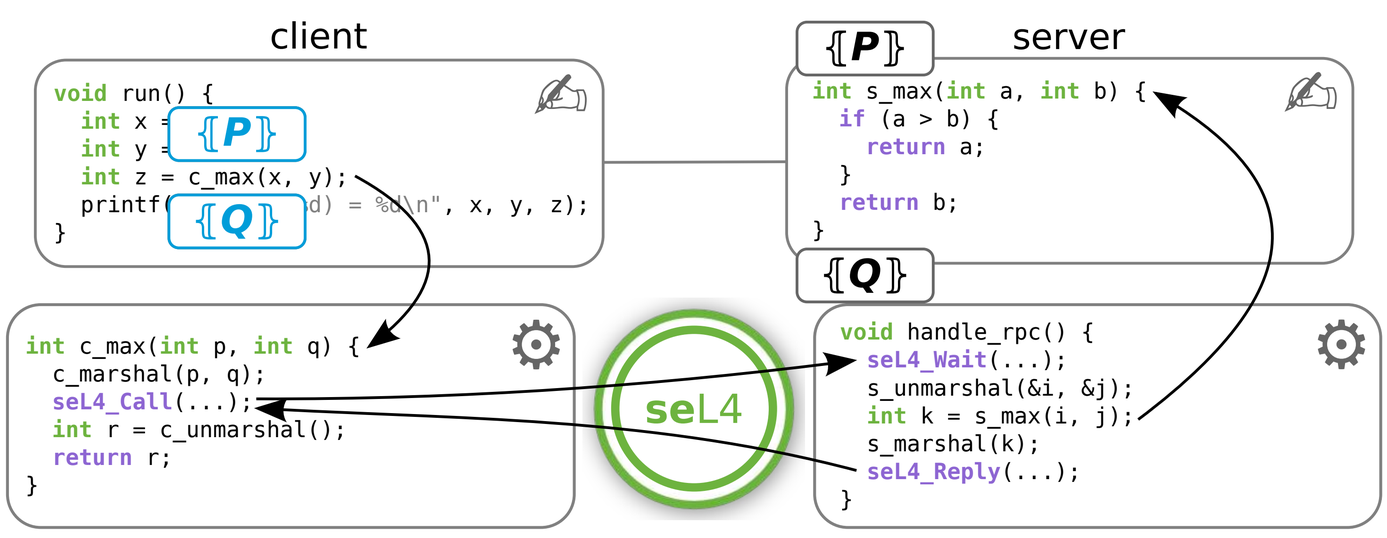

Composing Proofs

NICTA

theorem

{λ_. True}
s_max a b
*{λr _. r = **if** a > b **then** a **else** b}!*

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theorem

{λs. inv s}
__do__ c_marshal a b;
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r ← s_max a b;
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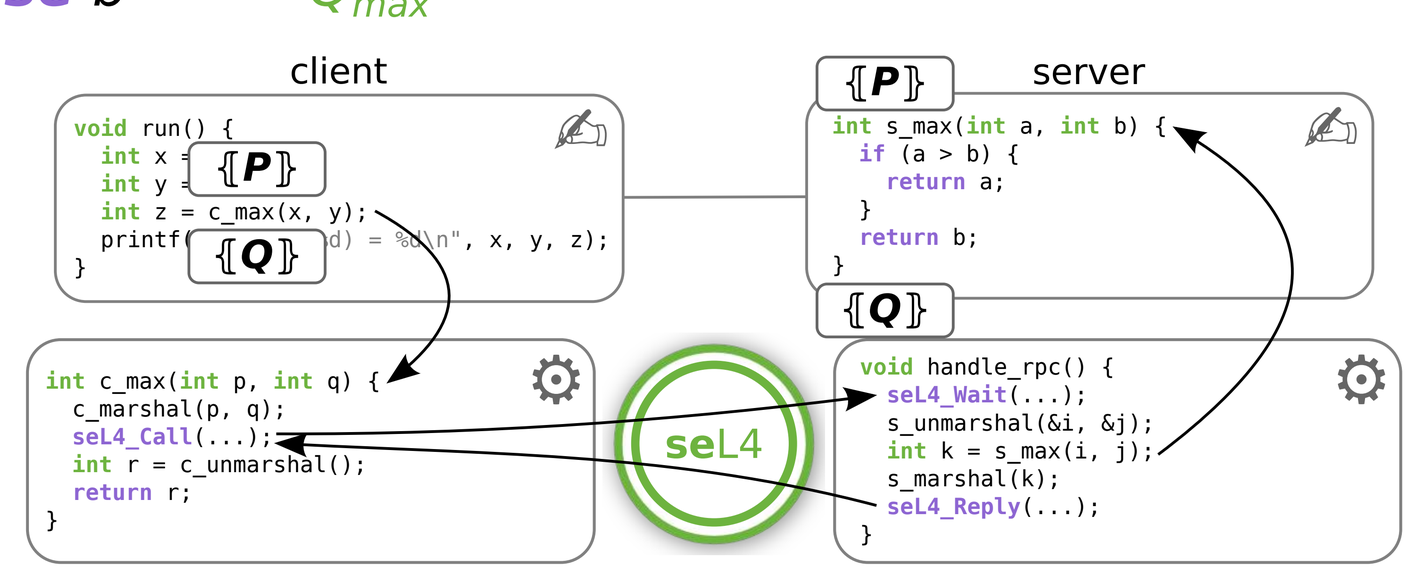
__od__
*{λr s. inv s ∧ r = **if** a > b **then** a **else** b}!*



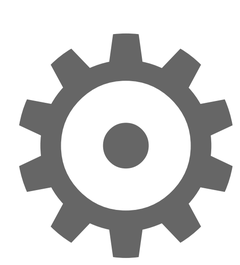
Challenges

NICTA

What is correctness?

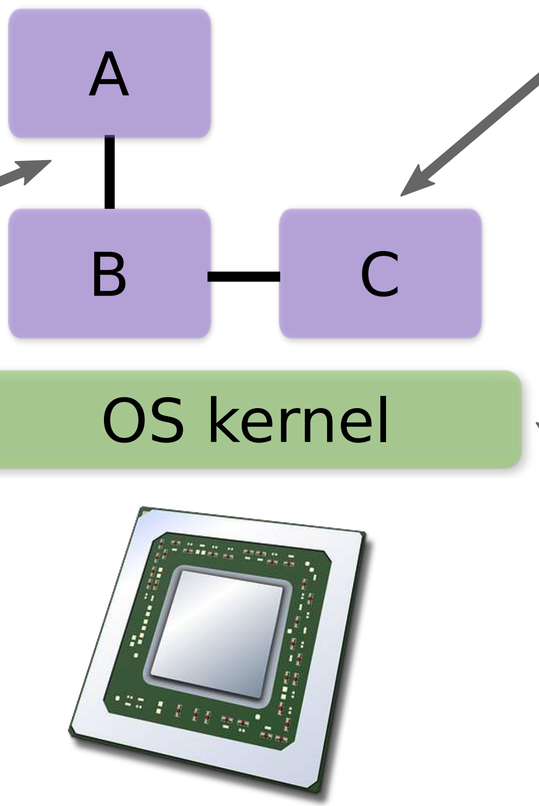
How do we prove it?

How do we automate it?



Generated Proofs for Generated Code

NICTA



components
- functionality
- policy
- >1 MLoC
- varied correctness criteria

CAmkES
- static component platform
- formal architectural model
- optimised for seL4
- designed for verification

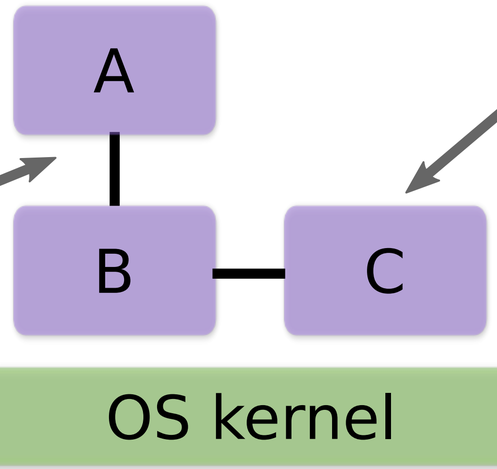
seL4
- 10,000 LoC microkernel
- functional correctness proof
- strong isolation properties
- fast and predictable

Generated Proofs for Generated Code

NICTA

proof obligations

components
- functionality
- policy
- >1 MLoC
- varied correctness criteria



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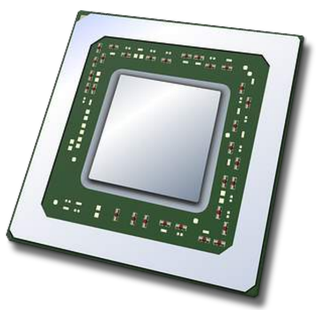

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Generated Proofs for Generated Code

NICTA

proof obligations

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A
B
C

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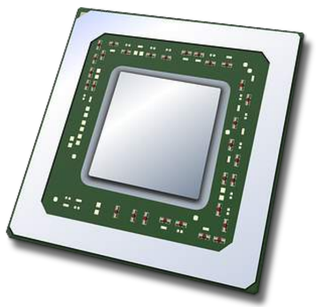
OS kernel



seL4
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