Towards a verified compiler for Distributed PlusCal

Presented at WPTE '25 on July 20, 2025

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(Université de Lorraine, CNRS, Inria, LORIA)

Overview

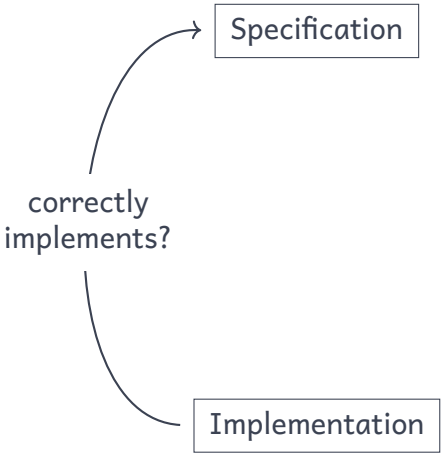
Implementation

Overview

Specification

Implementation

Overview



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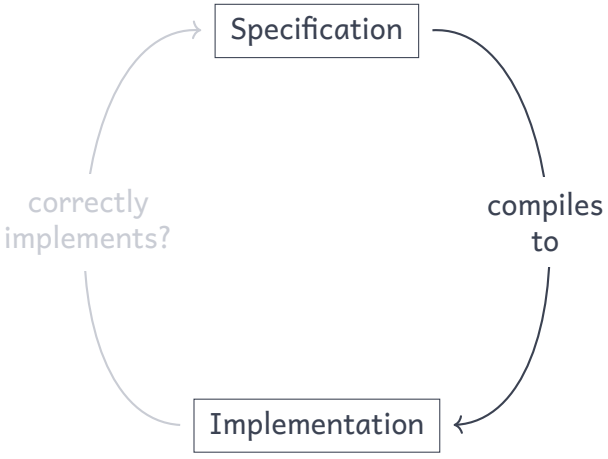
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correctly implements?

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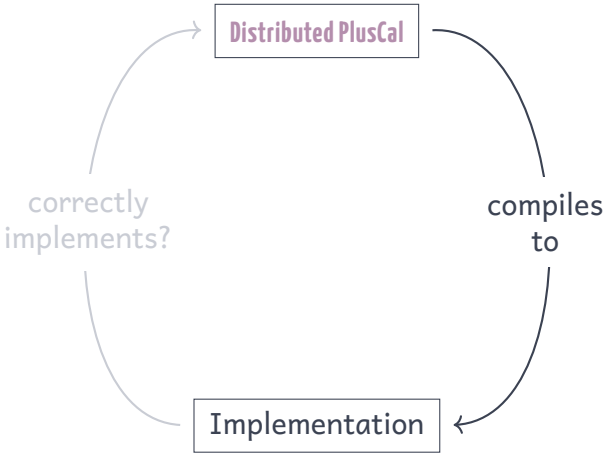
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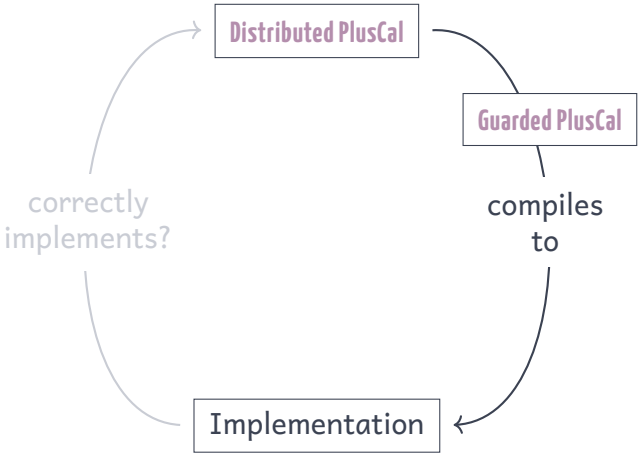
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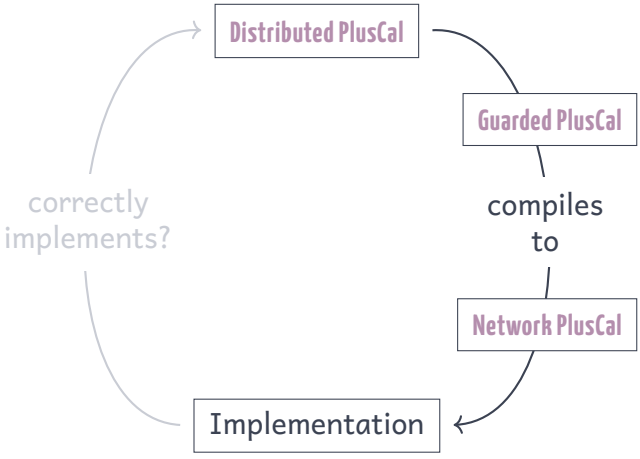
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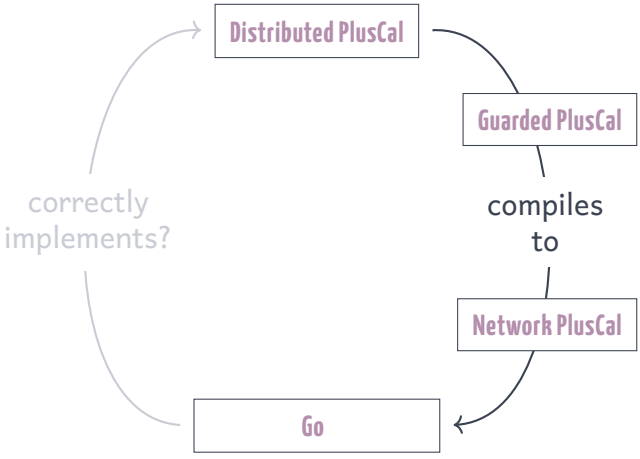
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A specification language for distributed/concurrent algorithms...

- ...translated to a TLA$^+$ specification.
- ...featuring message-passing and threading primitives.
- ...that looks like the C language.

```
algorithm PingPong {
    fifos ping, pong;

    process (Ping = 0)
        variable tmp1 = "";
    {
    rcv1:   receive(ping, tmp1);
            await tmp1 = "Ping";
            goto pong;
    pong:   send(pong, "Pong");
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    }

    process (Pong = 1)
        variable tmp2 = "";
    {
    ping:   send(ping, "Ping");
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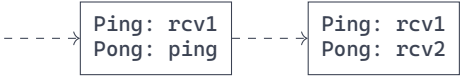

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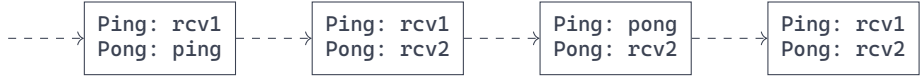

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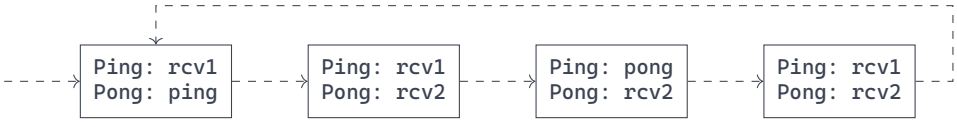

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- ⚠ No rollback mechanisms please!

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  - ✔ No need to rollback (most) assignments.

From Guarded PlusCal to Network PlusCal

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What if the first message in the channel `c` is $\not\exists$ `10`?

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process (Ping = 0)
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rcv1:   await Len(inbox) > 0;
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$\Rightarrow_{\mathcal{S}}$

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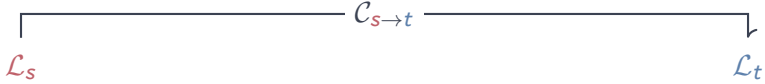
$\mathcal{L}_s$

$\mathcal{L}_t$


$\mathcal{C}_{s \to t}$
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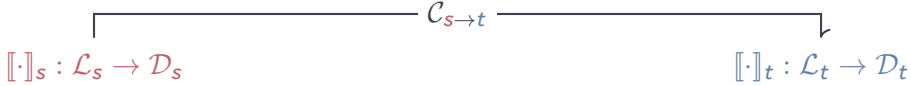
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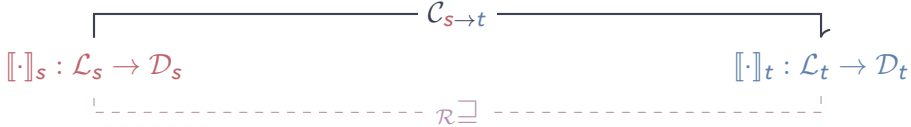

Definition (Behavior justification)

For $\mathcal{R} \subseteq \mathcal{D}_s \times \mathcal{D}_t$, a behavior $\sigma_t \in [\![P_t]\!]_t$ is $\mathcal{R}$-*justified by* a behavior $\sigma_s \in [\![P_s]\!]_s$ if $(\sigma_s, \sigma_t) \in \mathcal{R}$.

Definition (Partial correctness)

$\mathcal{C}_{s \to t}$ *preserves the semantics of* $\mathcal{L}_s$ if for all programs $P \in \mathcal{L}_s$, every (terminating) behavior of $[\![\mathcal{C}_{s \to t}(P)]\!]_t$ is $\mathcal{R}$-justified by some behavior of $[\![P]\!]_s$.

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$$\frac{M \vdash e \Downarrow v \qquad \tau = \mathit{out}(v)}{\langle\langle M, C\rangle, \tau, \langle M, C\rangle\rangle \in [\![\text{print } e]\!]} \qquad \frac{M \vdash e \Downarrow \text{TRUE} \qquad \tau = \varepsilon}{\langle\langle M, C\rangle, \tau, \langle M, C\rangle\rangle \in [\![\text{await } e]\!]}$$

$$\frac{\langle\langle M, C\rangle, \tau', \langle M'', C''\rangle\rangle \in [\![S]\!] \qquad \langle\langle M'', C''\rangle, \tau'', \langle M', C'\rangle\rangle \in [\![B]\!] \qquad \tau = \tau' * \tau''}{\langle\langle M, C\rangle, \tau, \langle M', C'\rangle\rangle \in [\![S; B]\!]}$$

$$\frac{C(c) = v \bullet vs \qquad C' = C(c := vs) \qquad M' = M(x := v) \qquad \tau = \varepsilon}{\langle\langle M, C\rangle, \tau, \langle M', C'\rangle\rangle \in [\![\text{receive}(c, x)]\!]}$$

Definition ($\sim \subseteq \mathit{State} \times \mathit{State}$)

$$\langle M_G, C_G \rangle \sim \langle M_N, C_N \rangle \overset{\text{def}}{\Leftrightarrow} \bigwedge \begin{cases} \forall\, v \neq \mathit{inbox}.\ M_G(v) = M_N(v) \\ \forall\, c \neq \mathit{mailbox}.\ C_G(c) = C_N(c) \\ C_G(\mathit{mailbox}) = M_N(\mathit{inbox}) +\!\!+ C_N(\mathit{mailbox}) \end{cases}$$

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Theorem (Partial correctness of $\mathcal{C}_{G \to N}$)

$\forall\, P \in$ Guarded PlusCal. $[\![\mathcal{C}_{G \to N}(P)]\!] \sqsubseteq_{\sim} [\![P]\!]$

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Proof idea:

Prove partial correctness of $\mathcal{E}$, $\mathcal{S}$ and $\mathcal{M}$ separately, then compose.

Conclusion

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Guarded PlusCal

Network PlusCal

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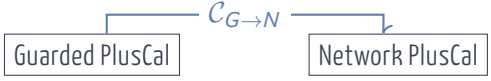

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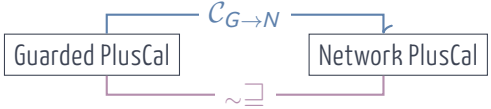
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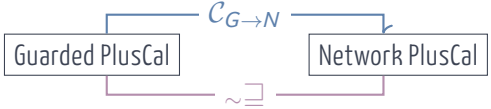

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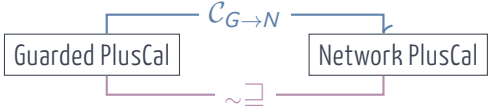

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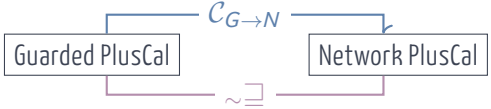

Fully mechanized/developed in the Coq proof assistant/programming language!

- Totalling ~**11k** LoC (~**8k** LoC of proofs)
- ~**400** lemmas & theorems

What next?

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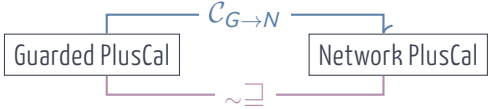

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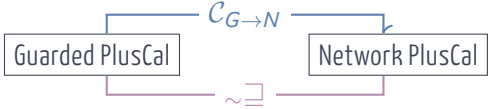

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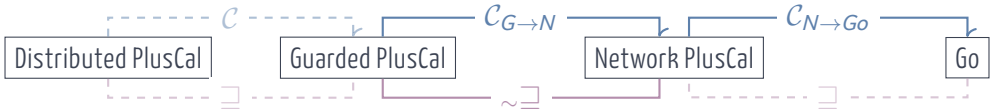
* Correctness of $\mathcal{C}_{N\to Go}$?

What next?

This is only the beginning!



Some challenges remain to be (fully) solved:

* Correctness of $\mathcal{C}_{N\to Go}$?
* How to relax the restrictions of Guarded PlusCal to improve on ergonomics?

Appendix

Behavior refinement $\sqsubseteq_{\mathcal{R}}$

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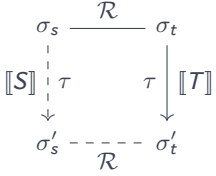
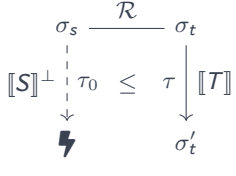


or



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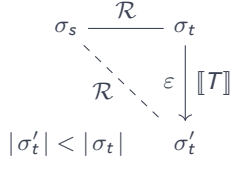

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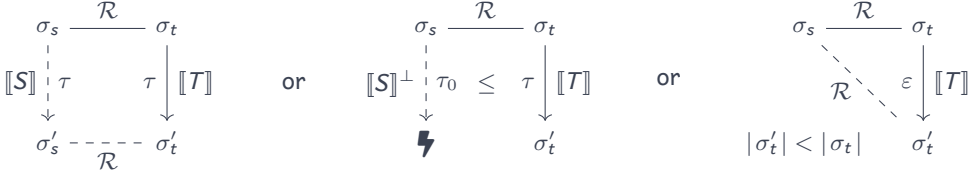

Appendix

Relaxing syntactical restrictions of Guarded PlusCal

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* Sometimes it is more convenient to write assignments before `await`s.

Relaxing syntactical restrictions of Guarded PlusCal

```
* if (e) { B } else { B' } ⟹
  either { await e; B } or { await \lnot e; B' }
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