FunTAL: Reasonably Mixing a Functional Language with Assembly

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Mixed language programs

Functional program

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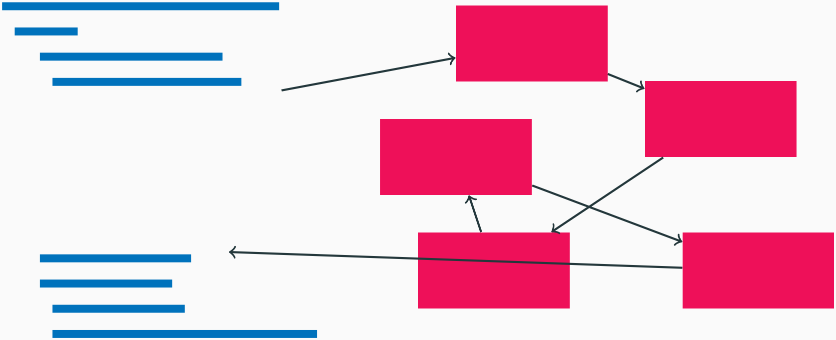
Functional program

Inline assembly



Questions we want to answer

How to safely mix assembly with high-level code?

How to reason about equivalence of mixed programs?

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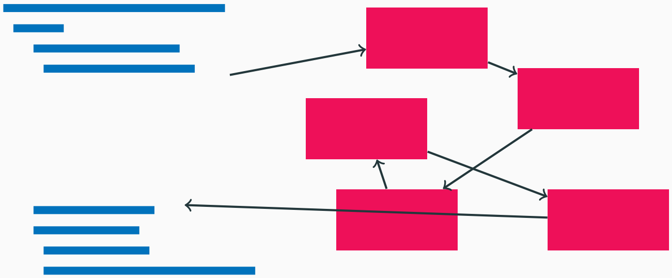
Prior approaches to mixing

Option 1: Translate high-level code into continuation-passing style to match assembly control-flow.



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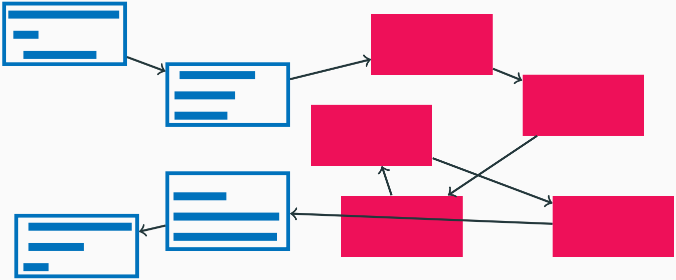

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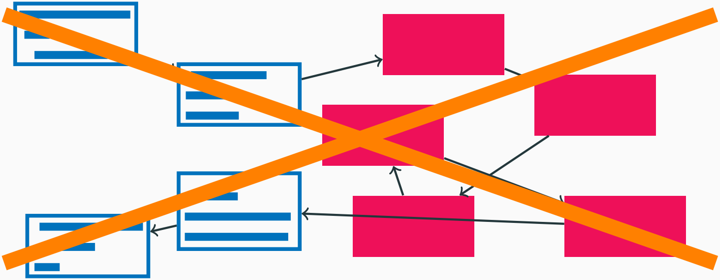

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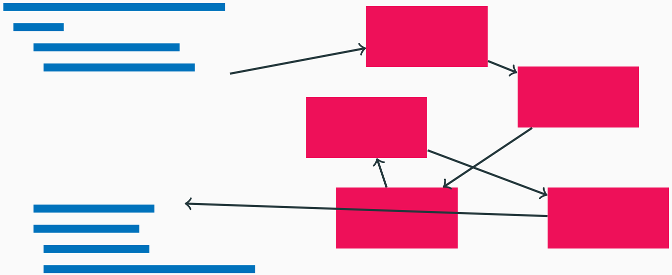

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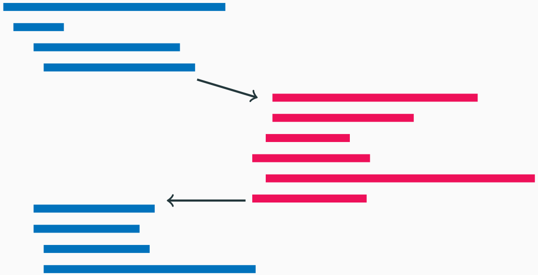

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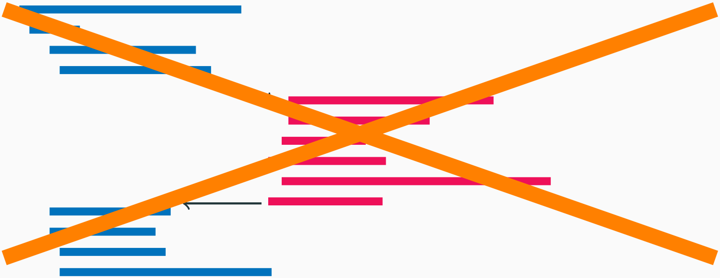

Our contributions

Allow safe mixing that allows **high-level code to remain high-level** and **low-level code to remain low-level**.

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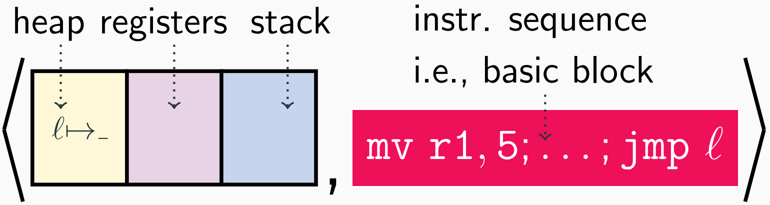
We do this via a novel notion of a **return marker**, which allows us to define the notion of an assembly **component**.

Fun: Functional language

- Simply typed lambda calculus (STLC)
- with (iso-)recursive types

TAL: Typed Assembly Language

[Morrisett, Crary, Glew, Walker '98]



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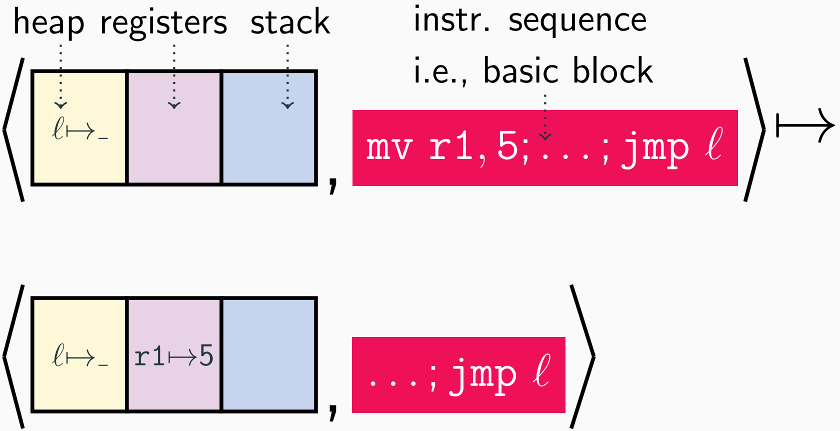

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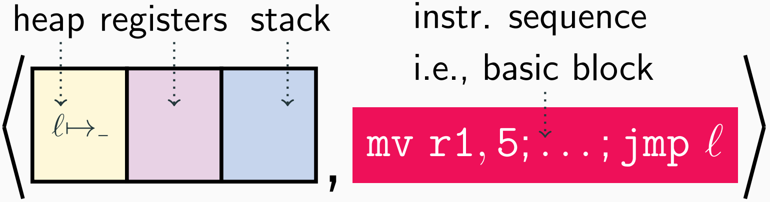

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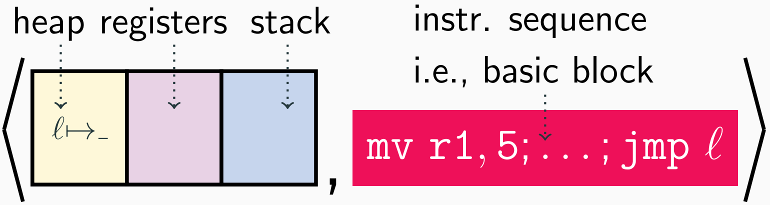

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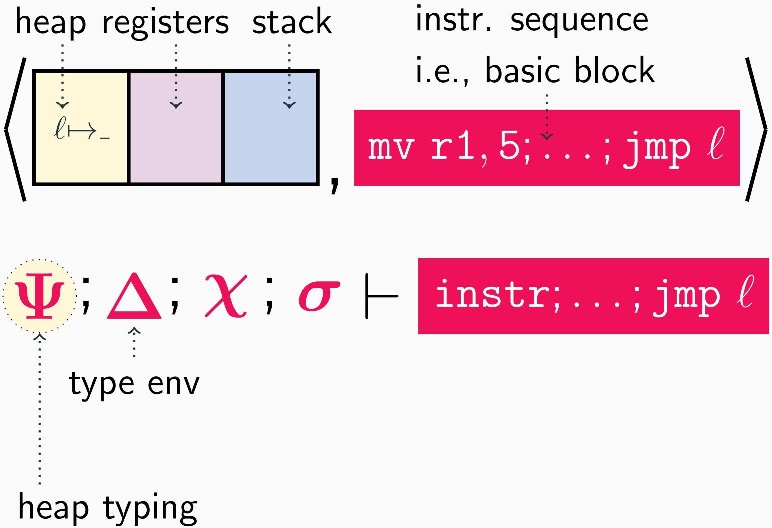

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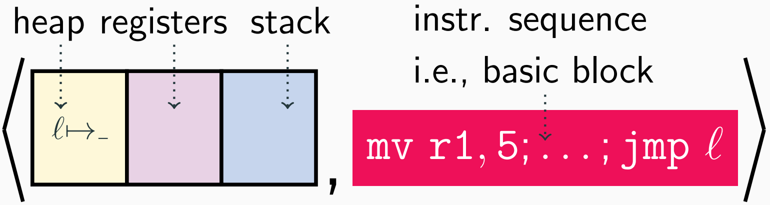

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register file typing

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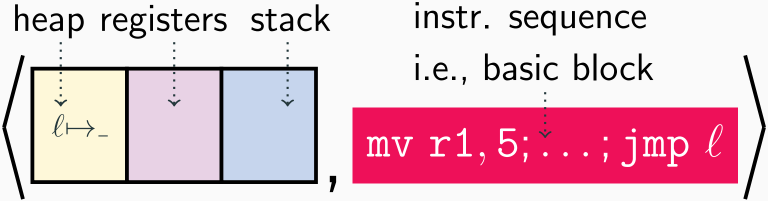

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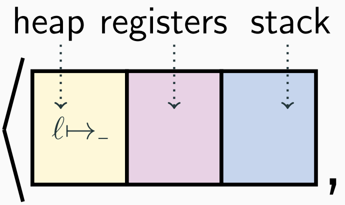

instr. sequence

i.e., basic block

$\langle \ldots , \texttt{mv r1}, 5; \ldots ; \texttt{jmp}\ \ell \rangle$

$$\Psi ; \Delta ; \chi ; \sigma \vdash \texttt{instr}; \ldots ; \texttt{jmp}\ \ell$$

$$\texttt{instr}; \ldots ; \texttt{jmp}\ \ell \ : \forall[\Delta].\{\chi ; \sigma\}$$

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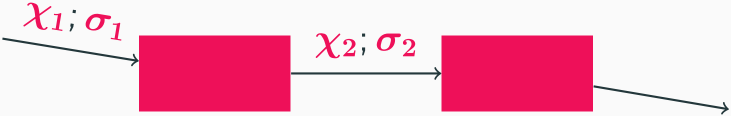

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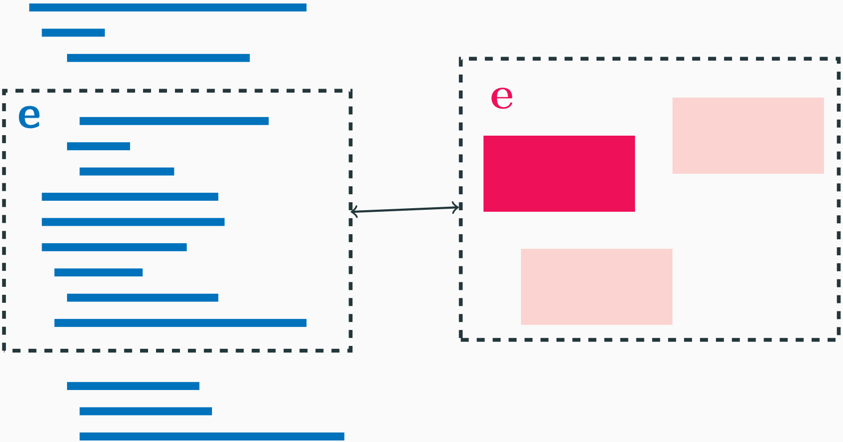

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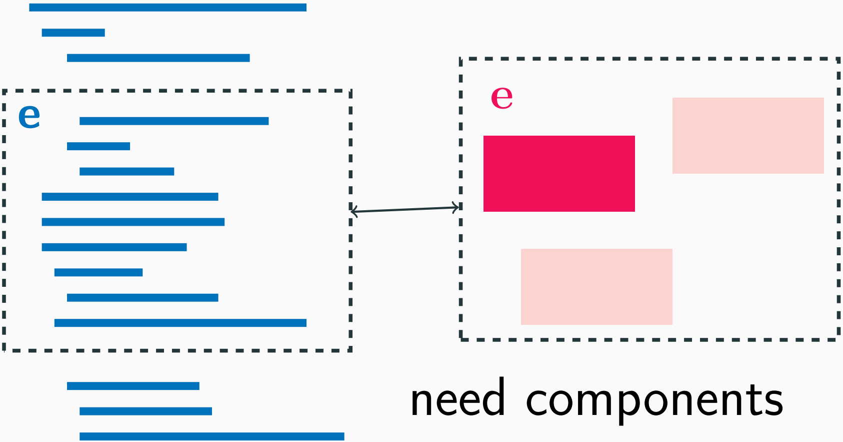

need components

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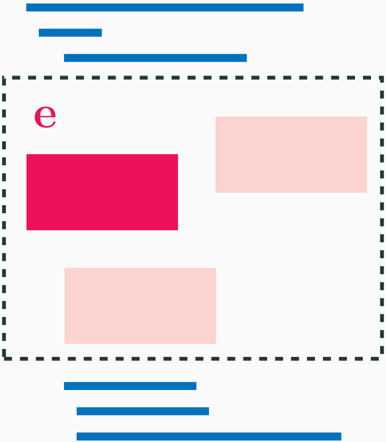

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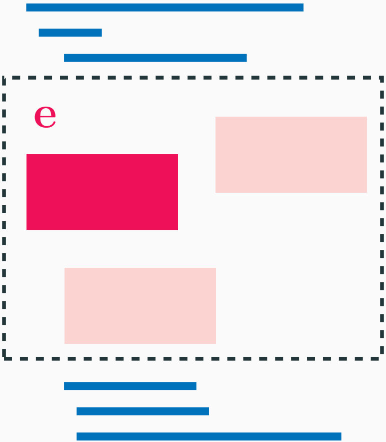

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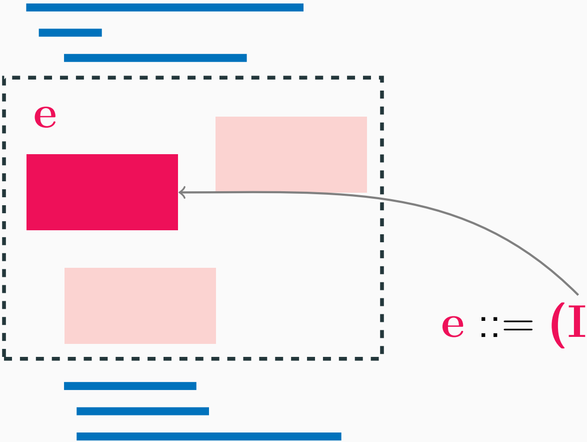

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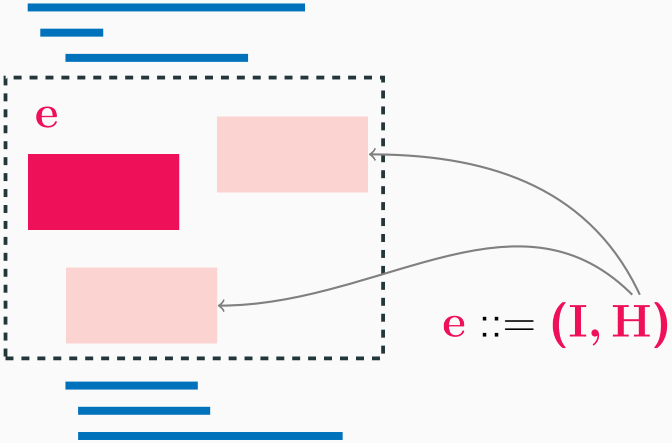

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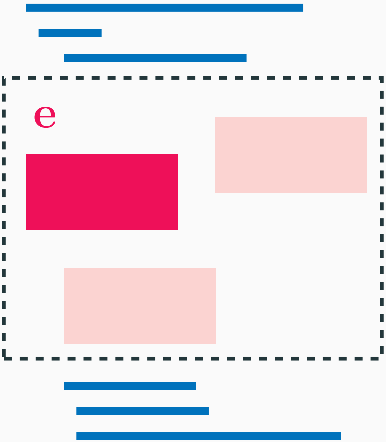

writing this program requires multi-language

Multi-languages in general

[Matthews-Findler '07]

Combine syntaxes from languages S and T and introduce boundary terms.

$$^{\tau}ST(e_T) \mapsto^* \ {}^{\tau}ST(v_T) \mapsto v_S$$

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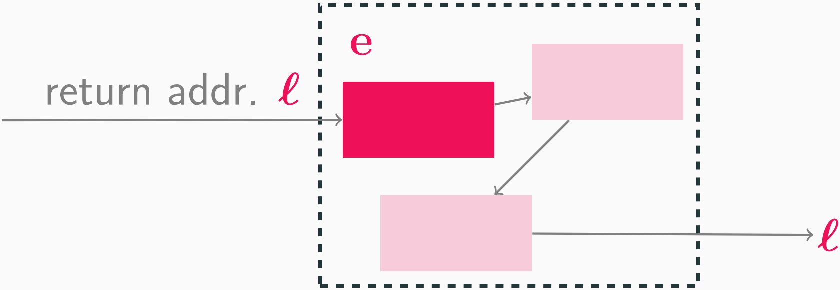
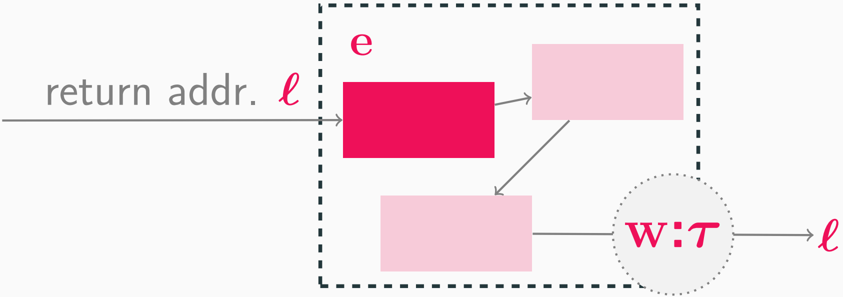


Return value passed to address



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return marker

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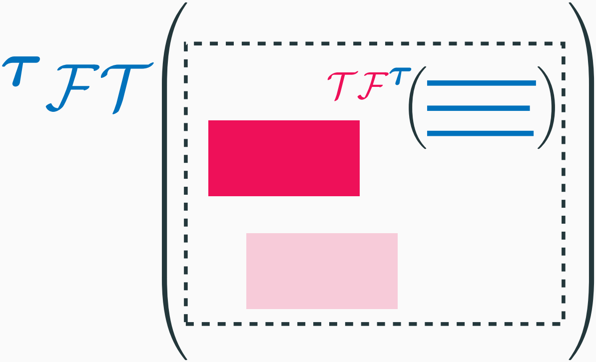
Embedding Fun in TAL



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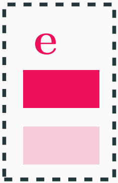

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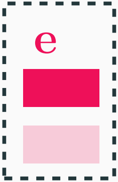

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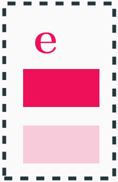

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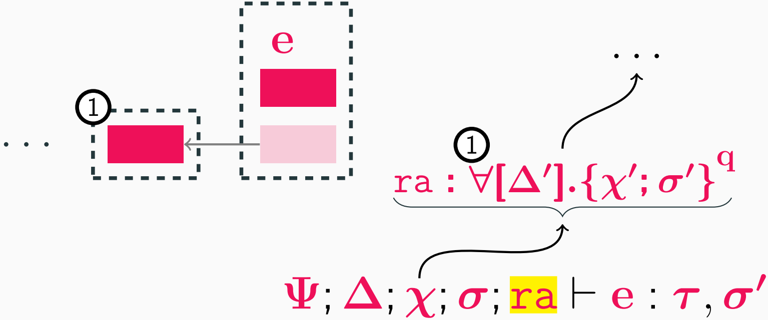

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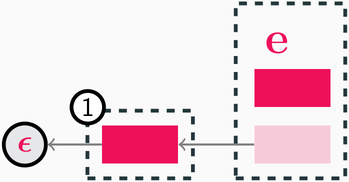

$$\underbrace{\mathtt{ra} : \forall[\Delta'].\{\chi^{\prime}; \sigma'\}}$$

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With polymorphic return marker ϵ, caller instantiates with where control flows next.

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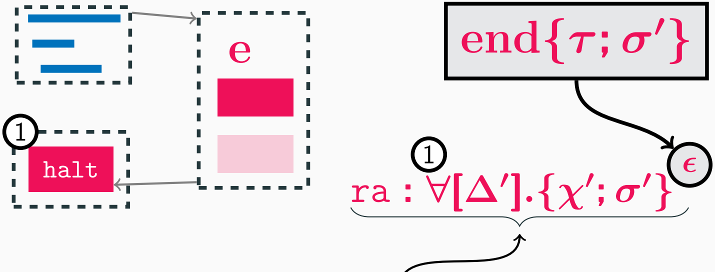

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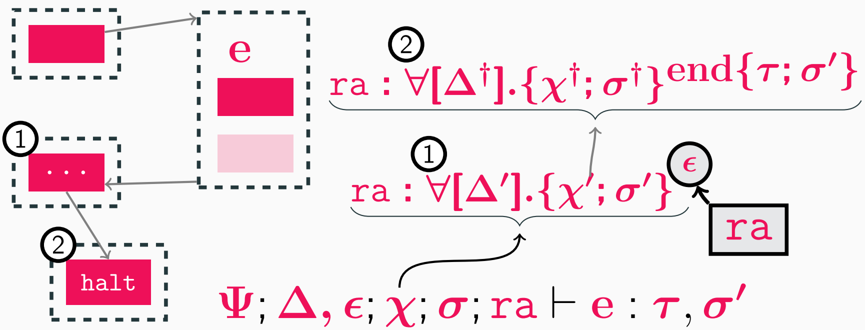

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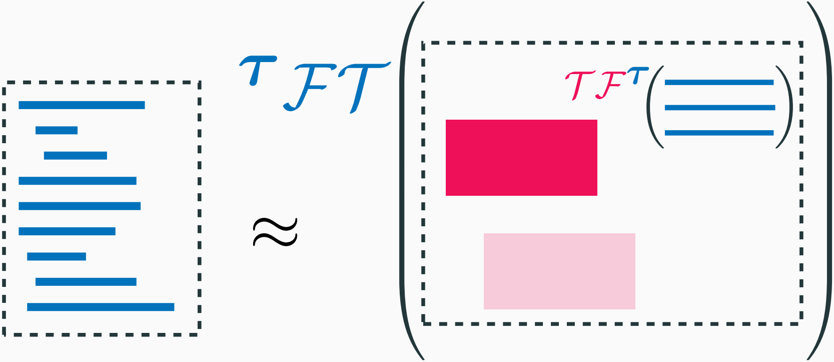
Proving program equivalence



Need logical relation for multi-language.

How logical relations work

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Write $\mathbf{v_1} \approx \mathbf{v_2}$ as $(\mathbf{v_1}, \mathbf{v_2}) \in \mathcal{V}(\boldsymbol{\tau})$.

Equivalence of functions

$$(\boldsymbol{\lambda} \mathbf{x}.\ \mathbf{e_1}, \boldsymbol{\lambda} \mathbf{x}.\ \mathbf{e_2}) \in \mathcal{V}(\boldsymbol{\tau_1} \to \boldsymbol{\tau_2})$$

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"Related inputs result in related outputs"

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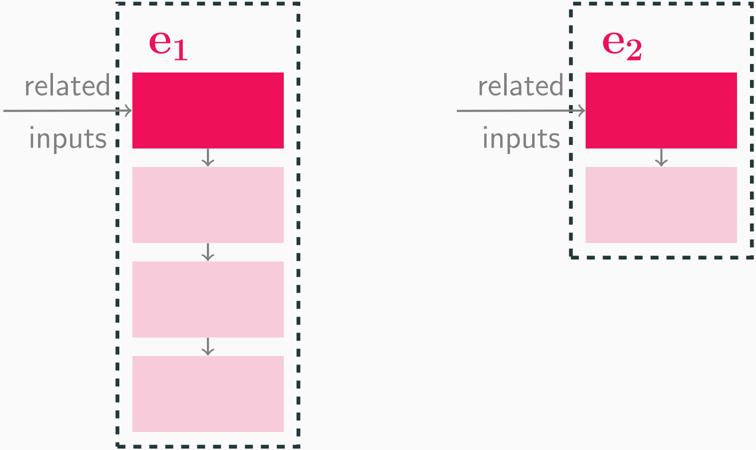
$$(\lambda x.\ e_1, \lambda x.\ e_2) \in \mathcal{V}(\tau_1 \to \tau_2)$$

$$\text{if } (v_1, v_2) \in \mathcal{V}(\tau_1) \implies$$
$$e_1[x \mapsto v_1] \approx e_2[x \mapsto v_2]$$

"Related inputs result in related outputs"

Equivalence of code blocks

$$\mathbf{e}_1 \approx \mathbf{e}_2$$



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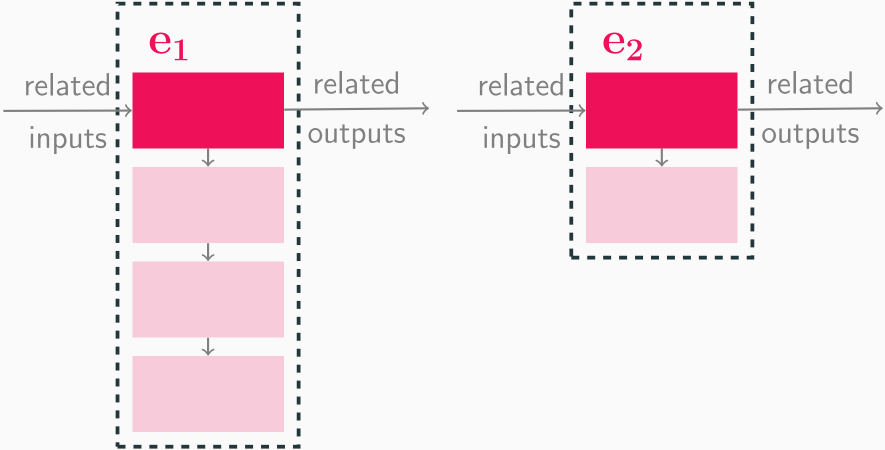

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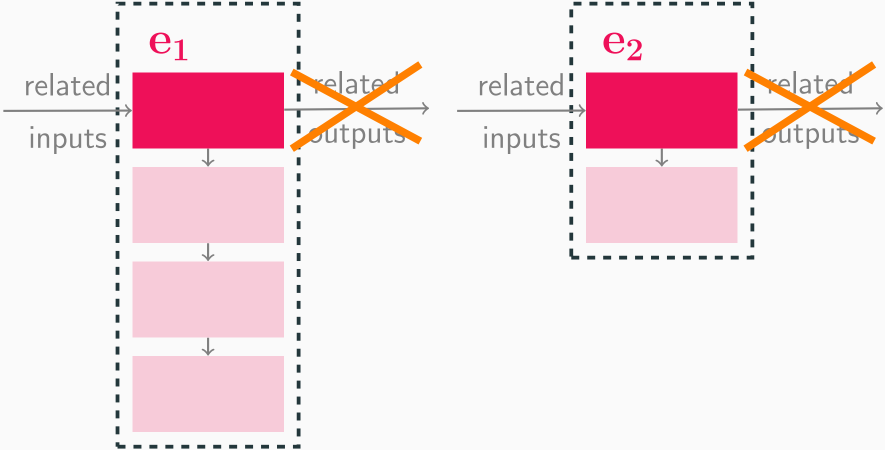

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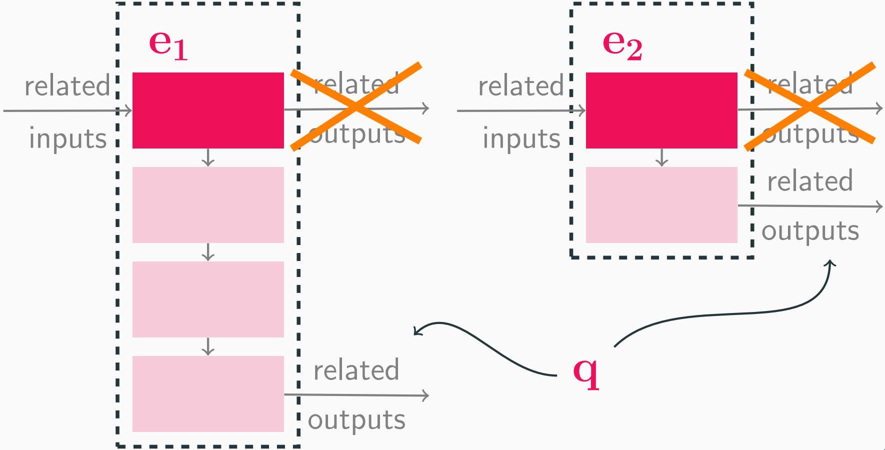

Questions we want to answer

How to safely mix assembly with high-level code? ✓

How to reason about equivalence of mixed programs?

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- Correctness for compilers targeting TAL (as suggested by *[Perconti-Ahmed '14]*).
- Using return markers for slightly higher level (i.e., SSA-like) languages.

Conclusion

Return markers allow **safe mixing of components** where high-level code remains high-level and low-level remains low-level.

See paper for (much) more detail and a web-based interpreter for FunTAL.