FunTAL: Reasonably Mixing a Functional Language with Assembly

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Christos Dimoulas,† Amal Ahmed*

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Mixed language programs

Functional program

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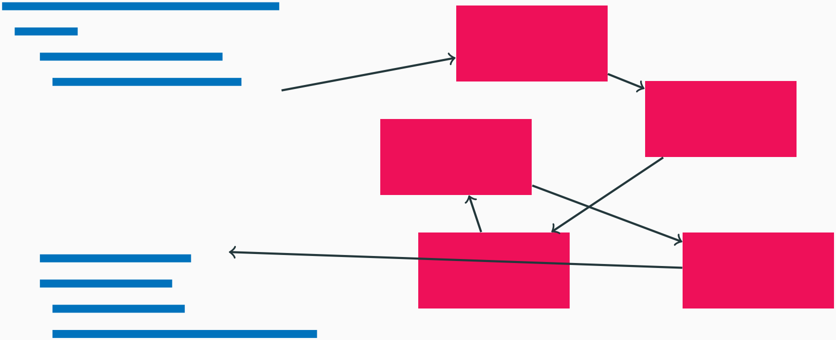
Functional program

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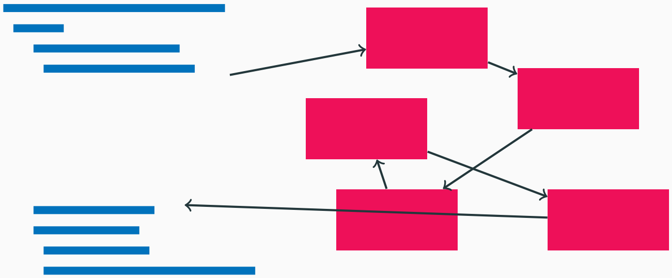
Option 1: Translate high-level code into continuation-passing style to match assembly control-flow.



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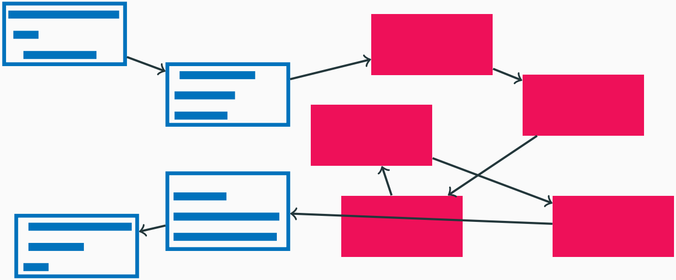

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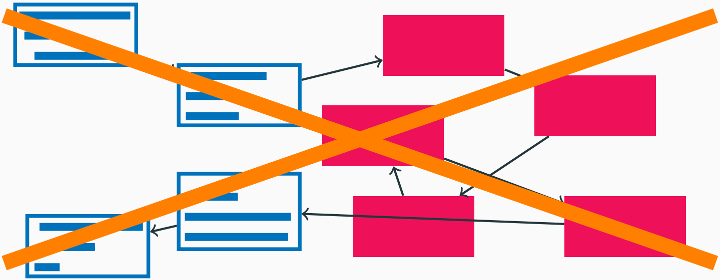

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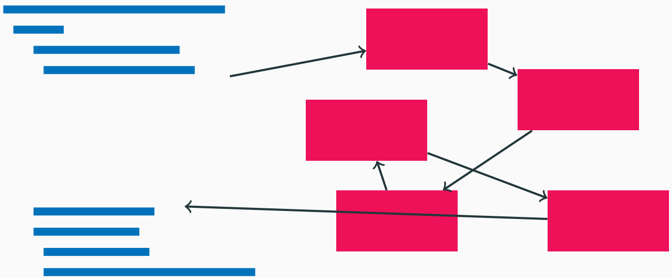

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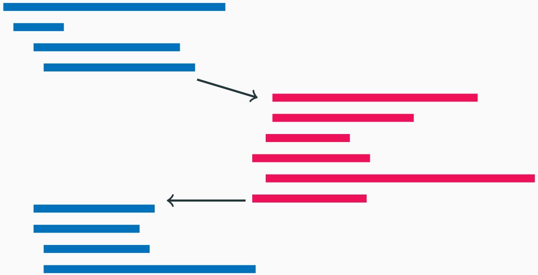

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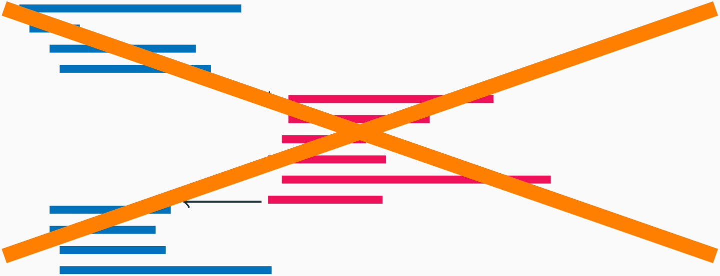

Our contributions

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]

heap registers stack

instr. sequence

i.e., basic block

$\left\langle \boxed{\ell \mapsto \_} \boxed{} \boxed{}, \boxed{\texttt{mv r1}, 5; \ldots; \texttt{jmp}\ \ell} \right\rangle$

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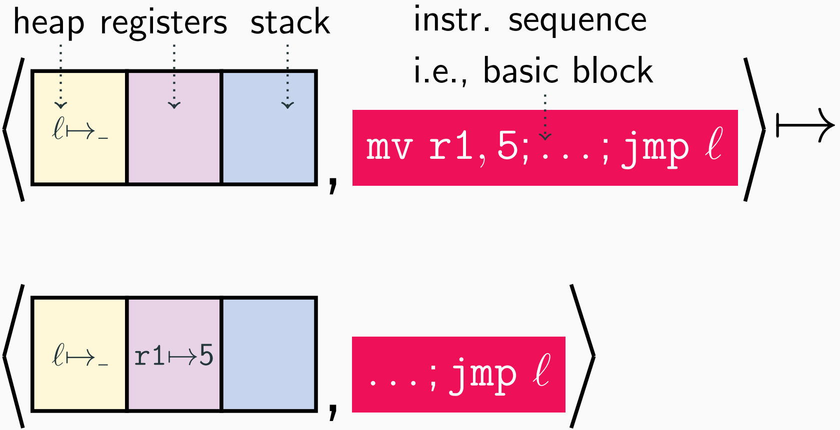

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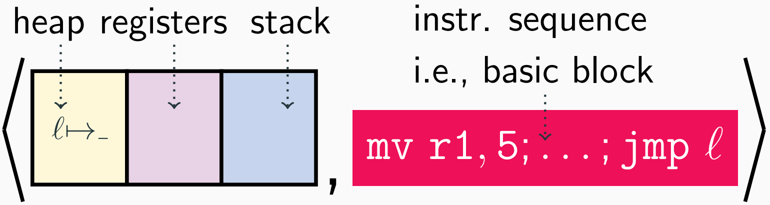

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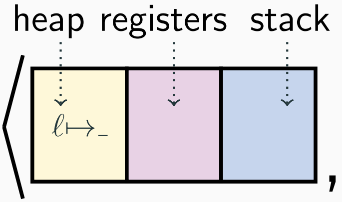

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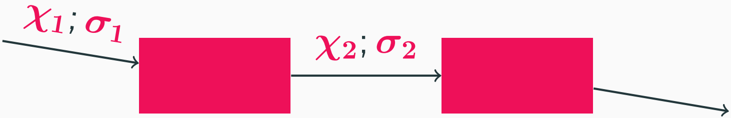

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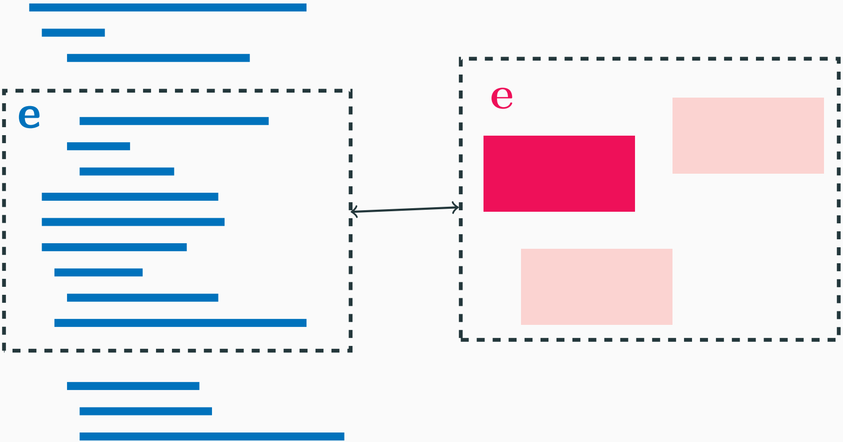

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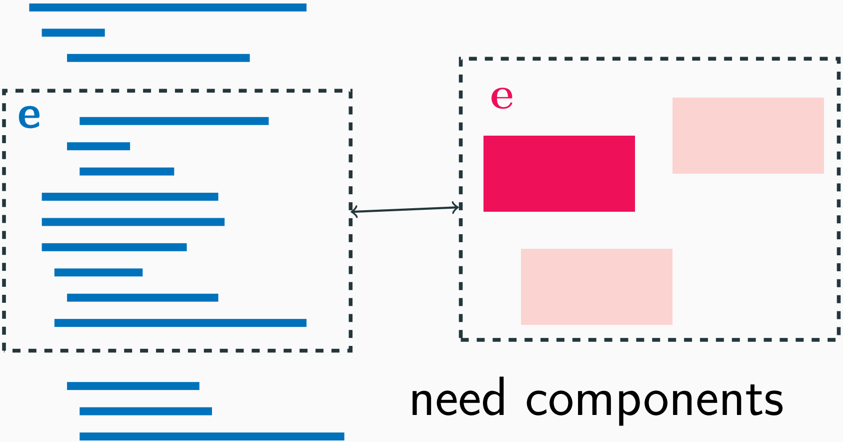

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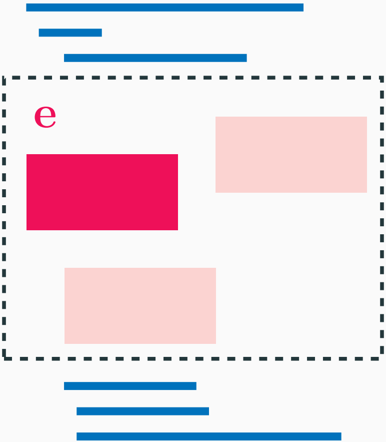

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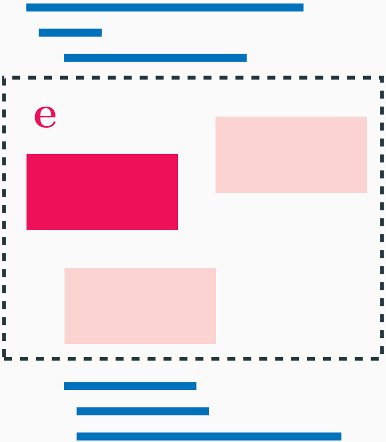

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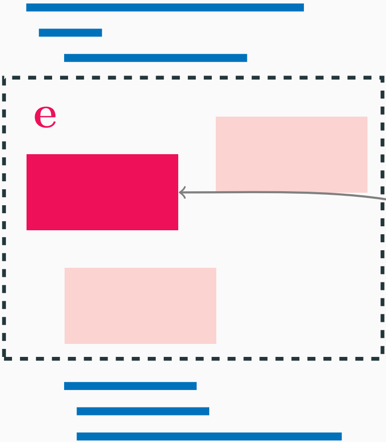

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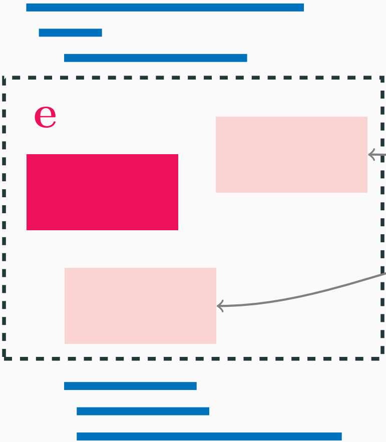

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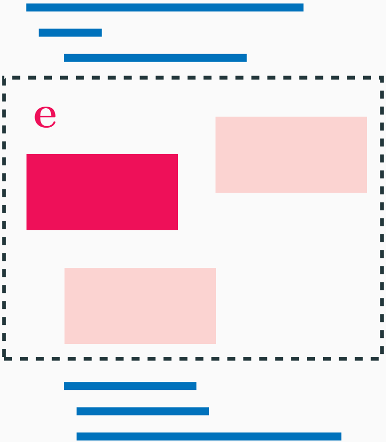

writing this
program requires
multi-language

Multi-languages in general

[Matthews-Findler 07]

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

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

$$TS^{\tau}(e_S) \mapsto^* TS^{\tau}(v_S) \mapsto v_T$$

“Reduce under boundary and then translate value.”

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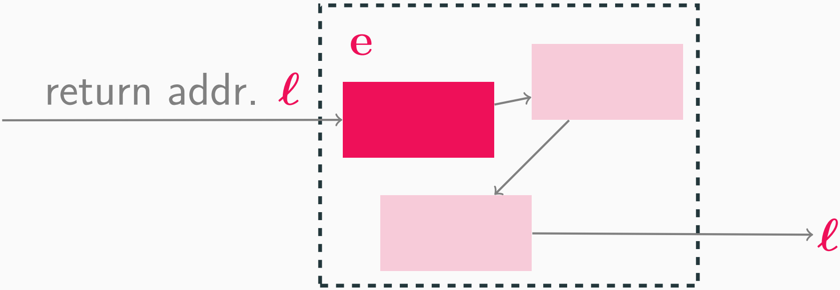
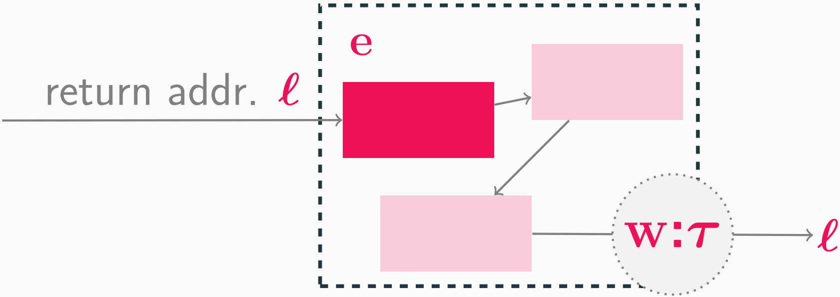
TAL components return to address



Return value passed to address



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return marker

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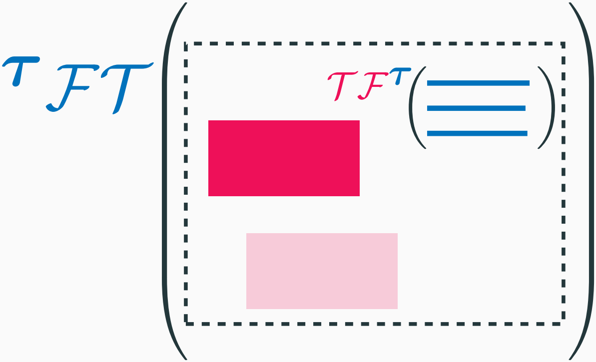
Embedding Fun in TAL



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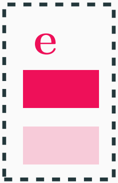
So far, $\mathbf{q}$ can be $\mathtt{ra}$, $\mathbf{n}$, $\mathbf{end}\{\boldsymbol{\tau};\boldsymbol{\sigma}\}$



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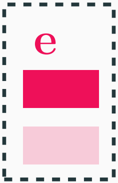

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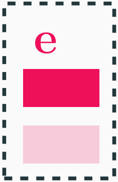

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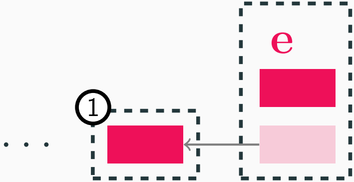

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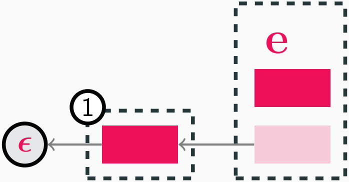

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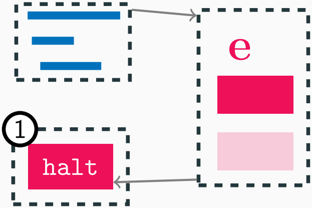

$$\boxed{\mathtt{end}\{\tau;\sigma'\}}$$

ϵ

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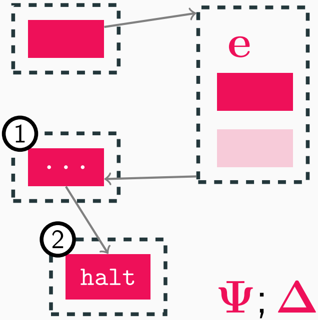

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$$\boxed{\mathtt{ra}}$$

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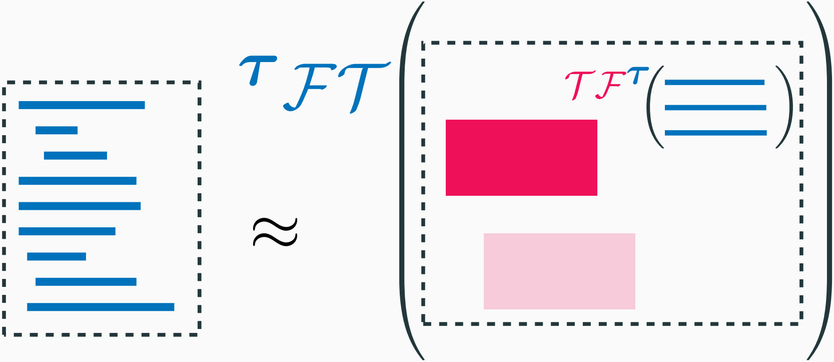
Proving program equivalence



Need logical relation for multi-language.

How logical relations work

$$\mathbf{e}{:}\boldsymbol{\tau} \approx {}^{\tau}\mathcal{FT}(\mathrm{e}{:}\boldsymbol{\tau}^{+}) \quad \text{means}$$

$$\mathbf{e} \mapsto^{*} \mathbf{v_1} \iff \mathcal{FT}(\mathrm{e}) \mapsto^{*} \mathbf{v_2}$$

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Write $\mathbf{v}_1 \approx \mathbf{v}_2$ as $(\mathbf{v}_1, \mathbf{v}_2) \in \mathcal{V}(\boldsymbol{\tau})$.

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$$(\boldsymbol{\lambda}\mathbf{x}.\ \mathbf{e}_1, \boldsymbol{\lambda}\mathbf{x}.\ \mathbf{e}_2) \in \mathcal{V}(\boldsymbol{\tau}_1 \to \boldsymbol{\tau}_2)$$

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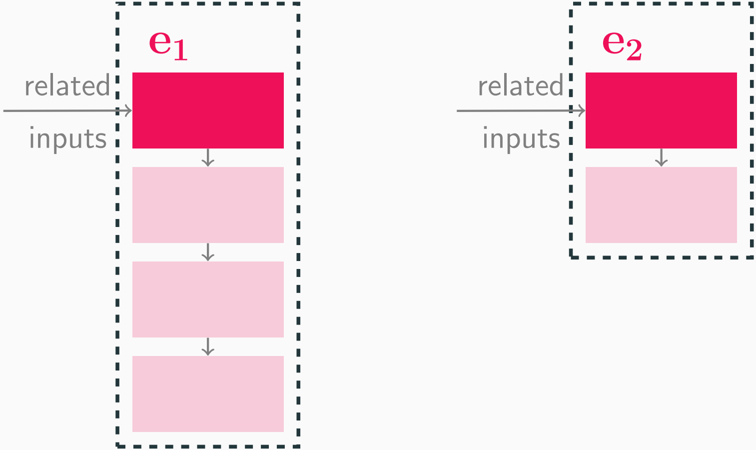
$$\mathbf{e}_1[\mathbf{x} \mapsto \mathbf{v}_1] \approx \mathbf{e}_2[\mathbf{x} \mapsto \mathbf{v}_2]$$

"Related inputs result in related outputs"

Equivalence of code blocks

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



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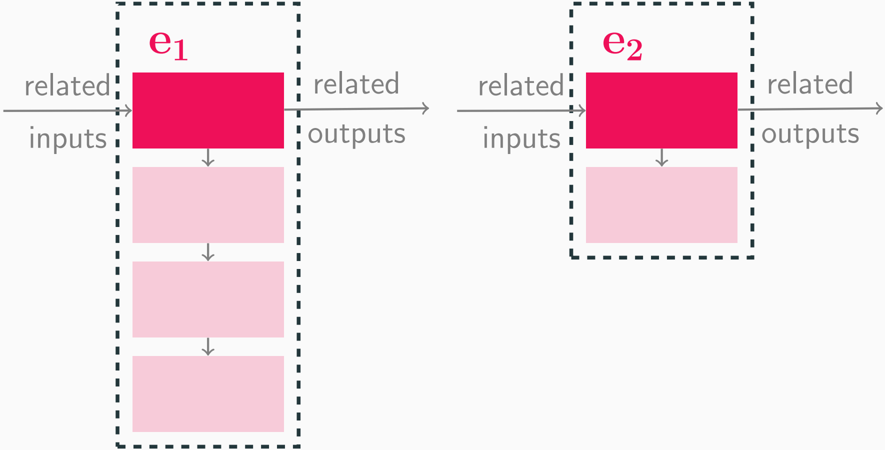

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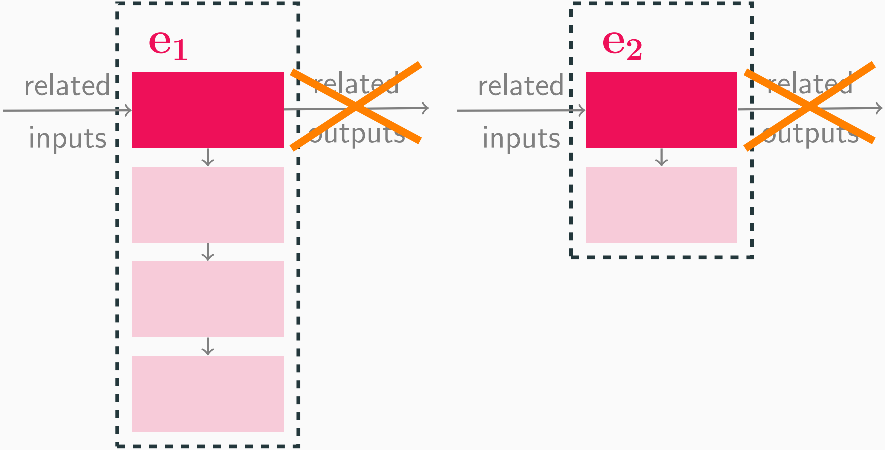

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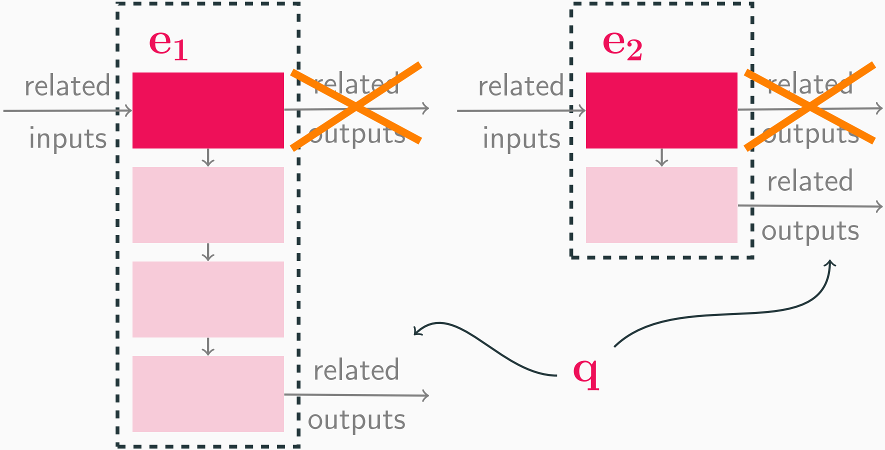

Questions we want to answer

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

How to reason about equivalence of mixed programs?

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- 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.