FunTAL: Reasonably Mixing a Functional Language with Assembly

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Christos Dimoulas,[†] Amal Ahmed[*]

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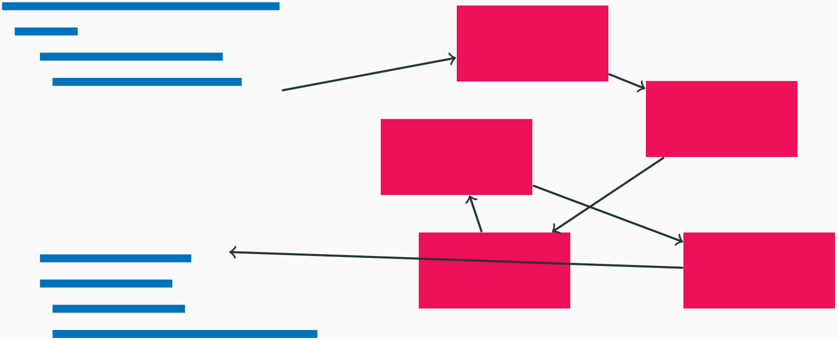
Mixed language programs

Functional program

Mixed language programs

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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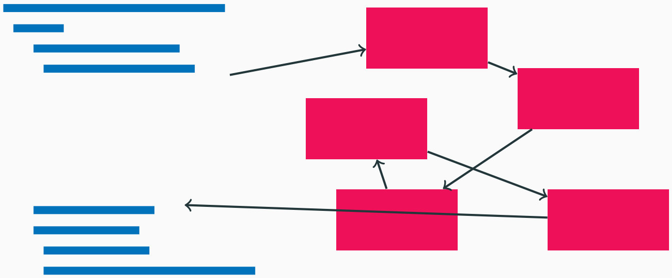
Prior approaches to mixing

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



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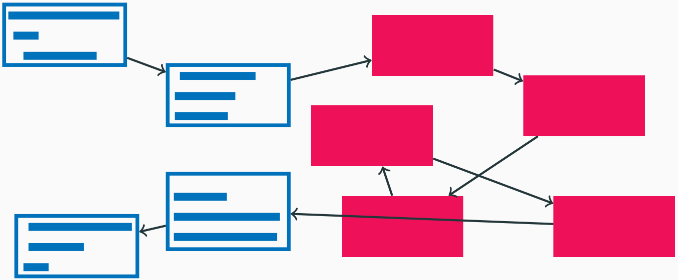

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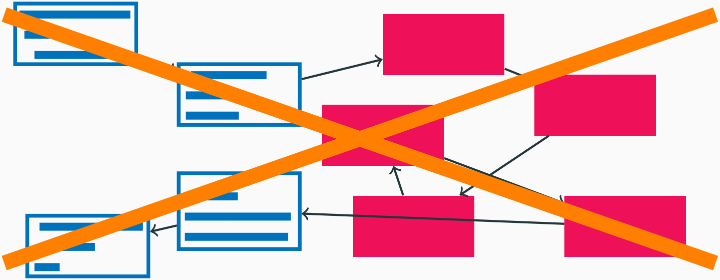

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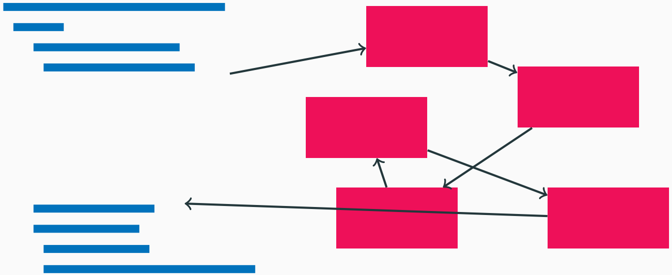

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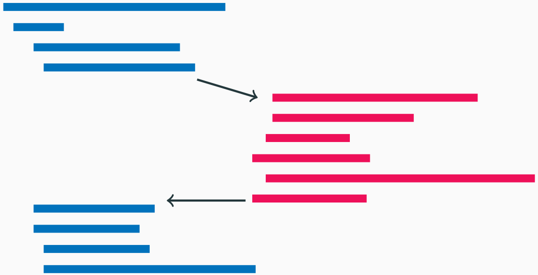

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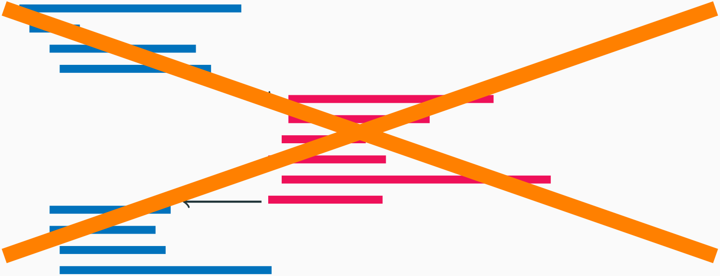

Our contributions

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

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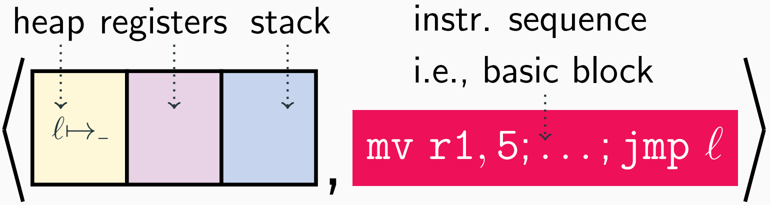
We do this via a novel notion of a **return marker**, which allows us to define the notion of an assembly **component**.

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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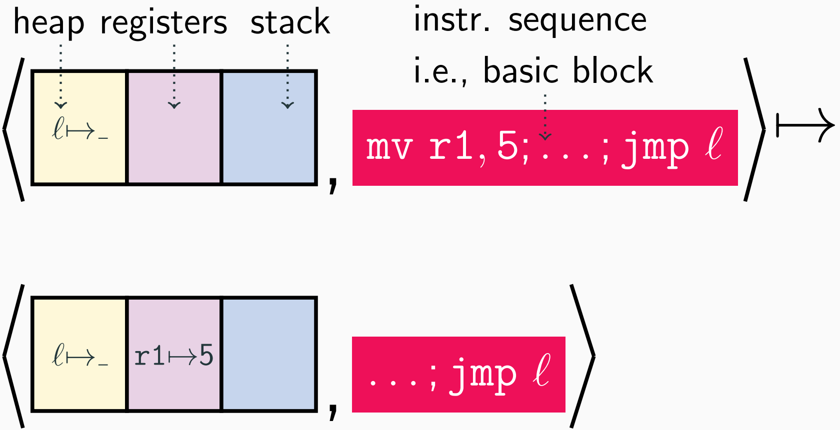

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[Morrisett, Crary, Glew, Walker '98]

heap registers stack

instr. sequence

i.e., basic block

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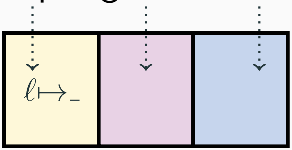

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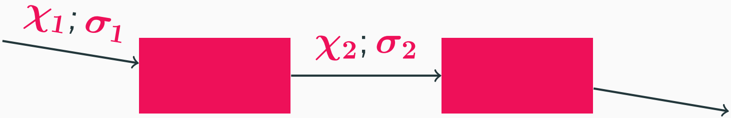

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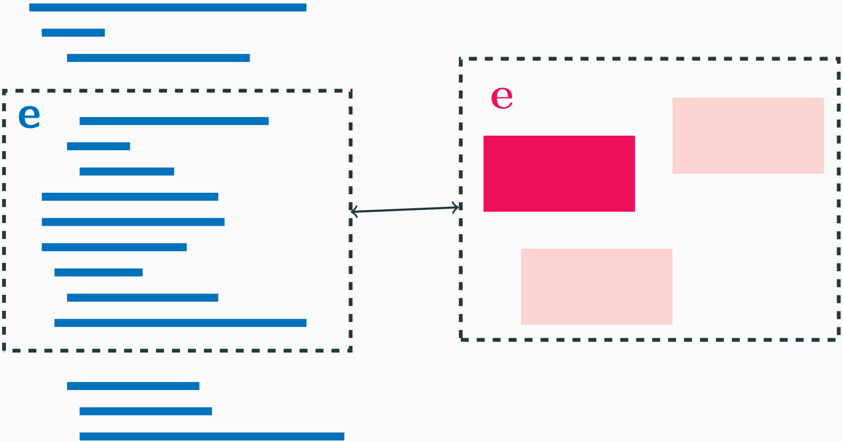

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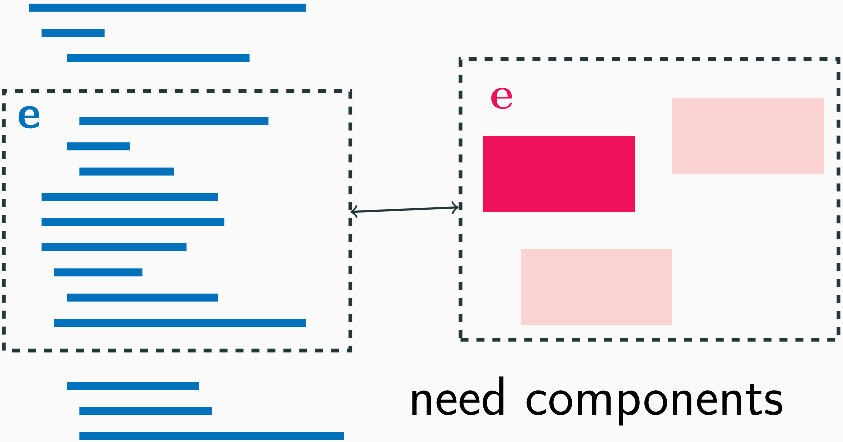

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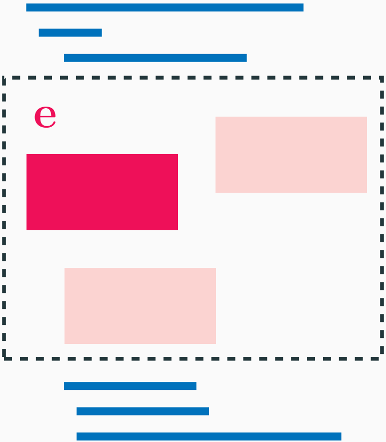

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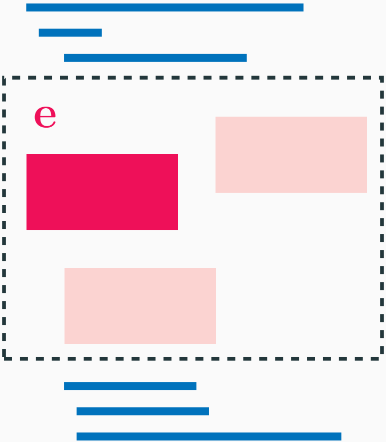

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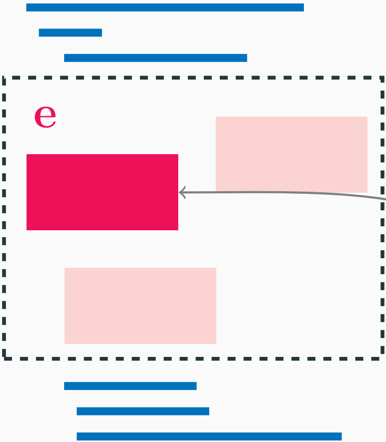

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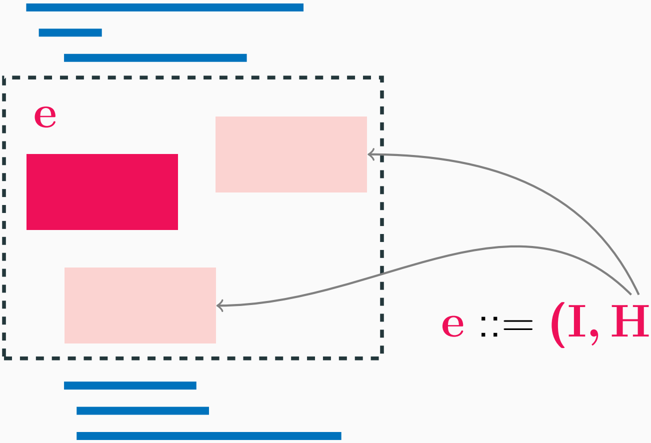

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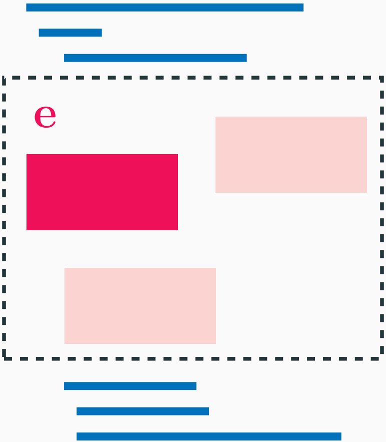

writing this program requires multi-language

Multi-languages in general

[Matthews-Findler '07]

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

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

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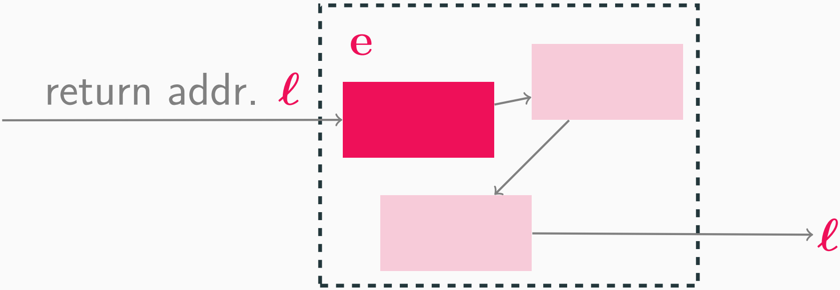
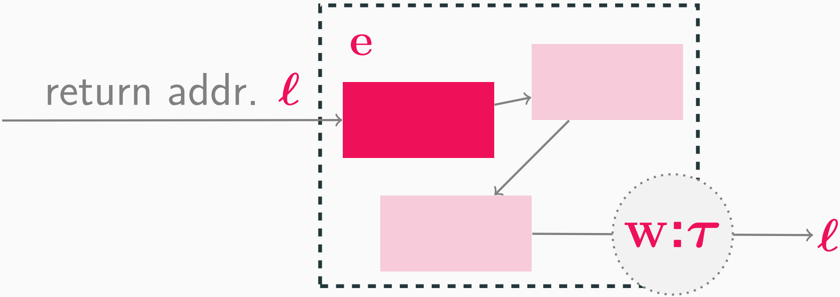
TAL components return to address



Return value passed to address



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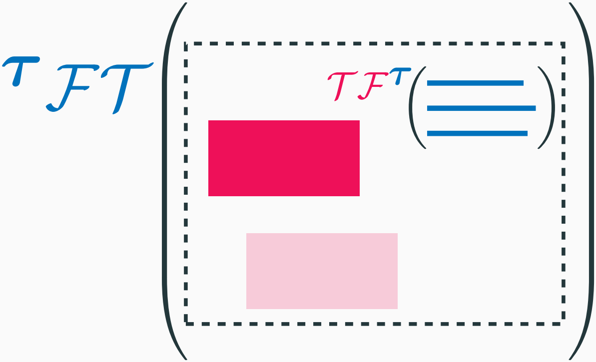
Embedding Fun in TAL



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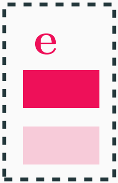

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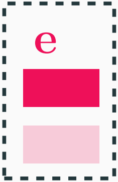

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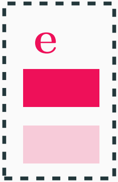

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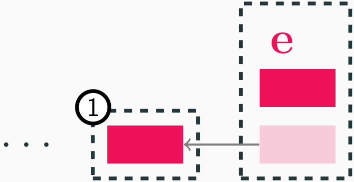

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$$\underbrace{\mathtt{ra} : \forall[\Delta'].\{\chi';\sigma'\}^{\mathrm{q}}}$$

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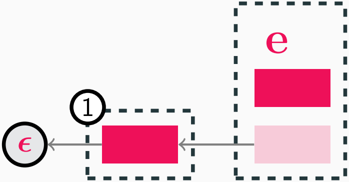

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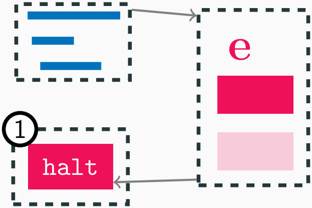

$$\boxed{\mathbf{end}\{\tau;\sigma'\}}$$

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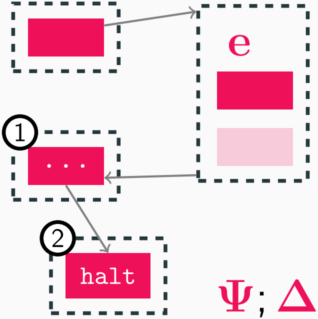

$$\overbrace{\texttt{ra} : \forall[\Delta^{\dagger}].\{\chi^{\dagger}; \sigma^{\dagger}\}^{\mathbf{end}\{\tau;\sigma'\}}}^{②}$$

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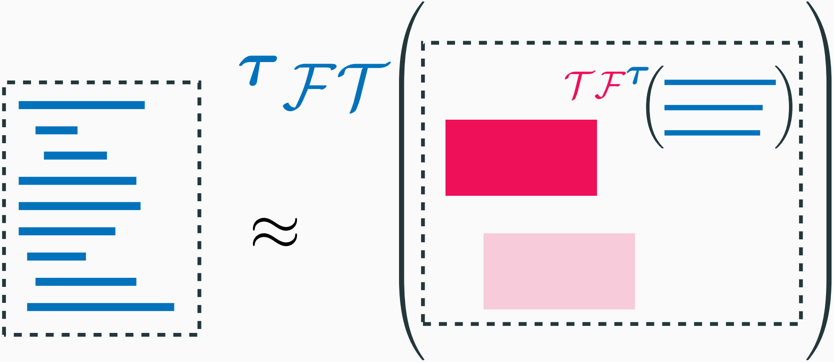
Proving program equivalence



Need logical relation for multi-language.

How logical relations work

$$\mathbf{e}{:}\boldsymbol{\tau} \approx {}^{\tau}\mathcal{F}\mathcal{T}(\mathrm{e}{:}\boldsymbol{\tau}^{+}) \;\; \text{means}$$

$$\mathbf{e} \mapsto^{*} \mathbf{v}_1 \iff \mathcal{F}\mathcal{T}(\mathrm{e}) \mapsto^{*} \mathbf{v}_2$$

$$\text{and } \mathbf{v}_1 \approx \mathbf{v}_2$$

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

Equivalence of functions

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

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"Related inputs result in related outputs"

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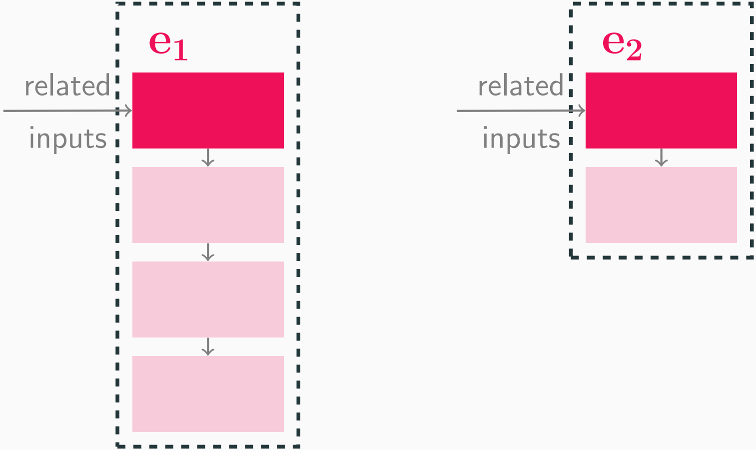
$$\mathbf{e}_1[\mathbf{x} \mapsto \mathbf{v}_1] \approx \mathbf{e}_2[\mathbf{x} \mapsto \mathbf{v}_2]$$

"Related inputs result in related outputs"

Equivalence of code blocks

$$\mathbf{e_1} \approx \mathbf{e_2}$$



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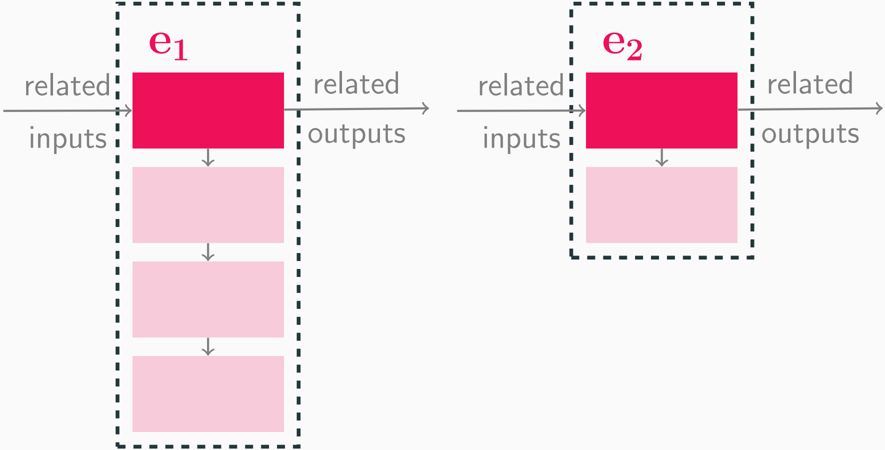

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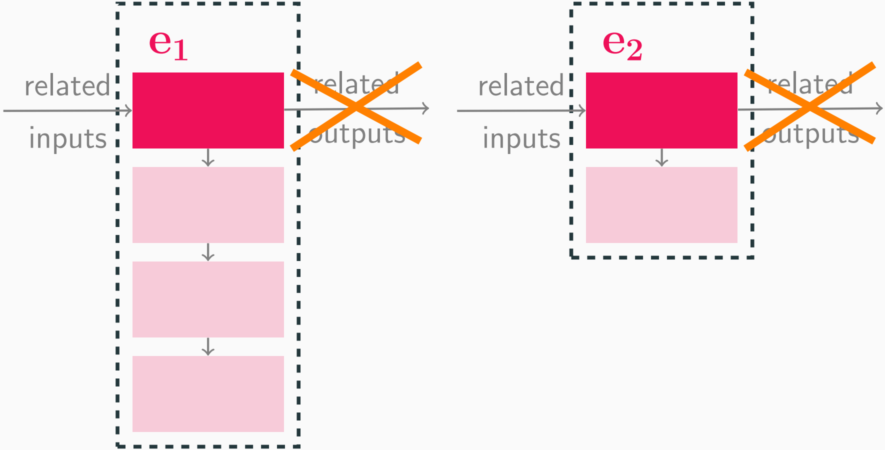

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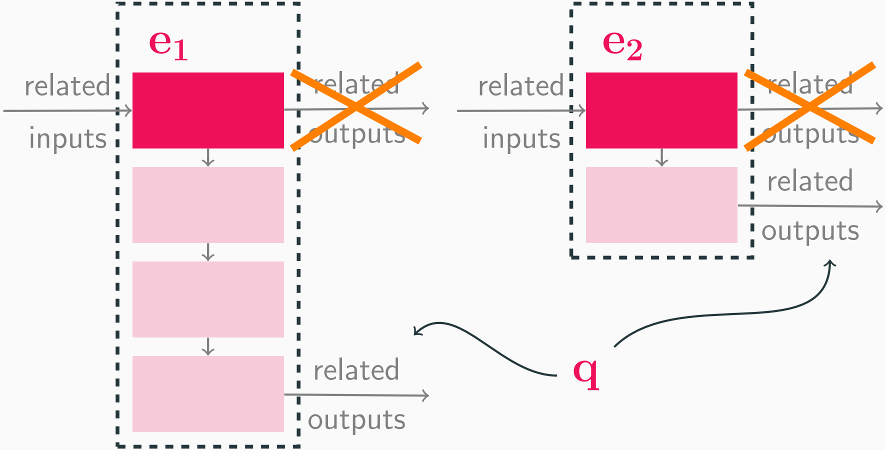

Questions we want to answer

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

How to reason about equivalence of mixed programs?

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- 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.