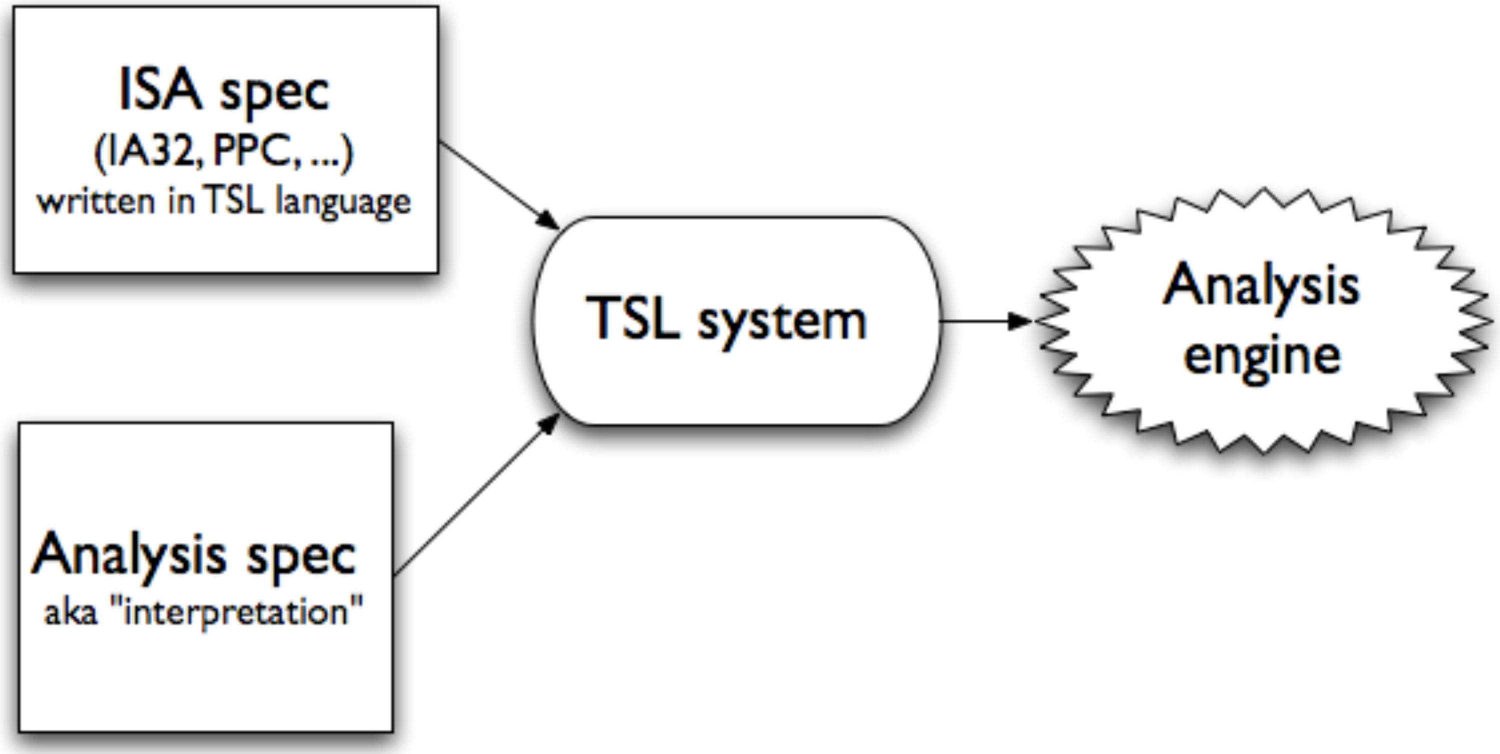
A system for testing specifications of CPU semantics

or,
What I did on my summer vacation

Lindsey Kuper

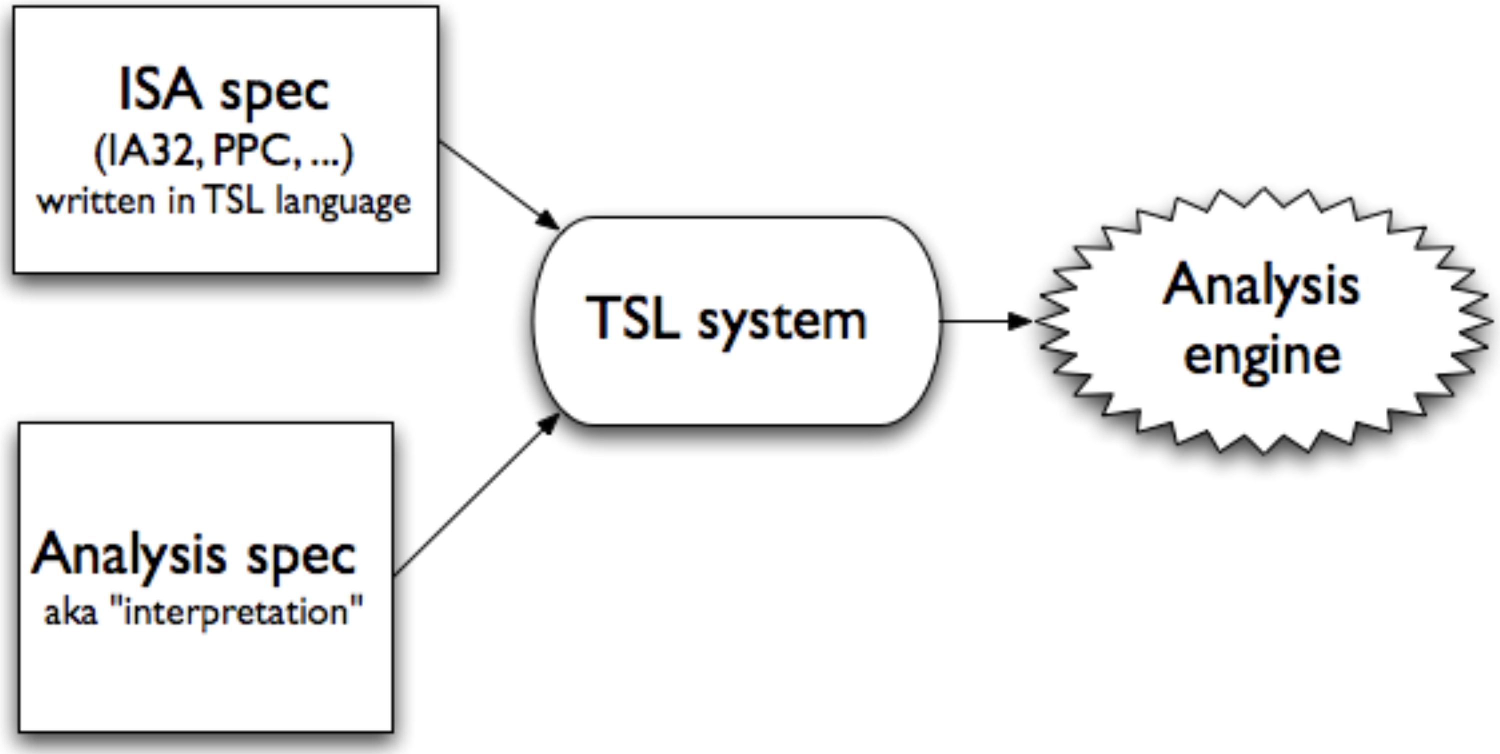
The TSL testing problem

The TSL testing problem



Lim, J, and Reps, T. , “A System for Generating Static Analyzers from Machine Instructions”, CC ’08

The TSL testing problem



ISA spec

(IA32, PPC, ...)

written in TSL language

TSL system

Analysis engine

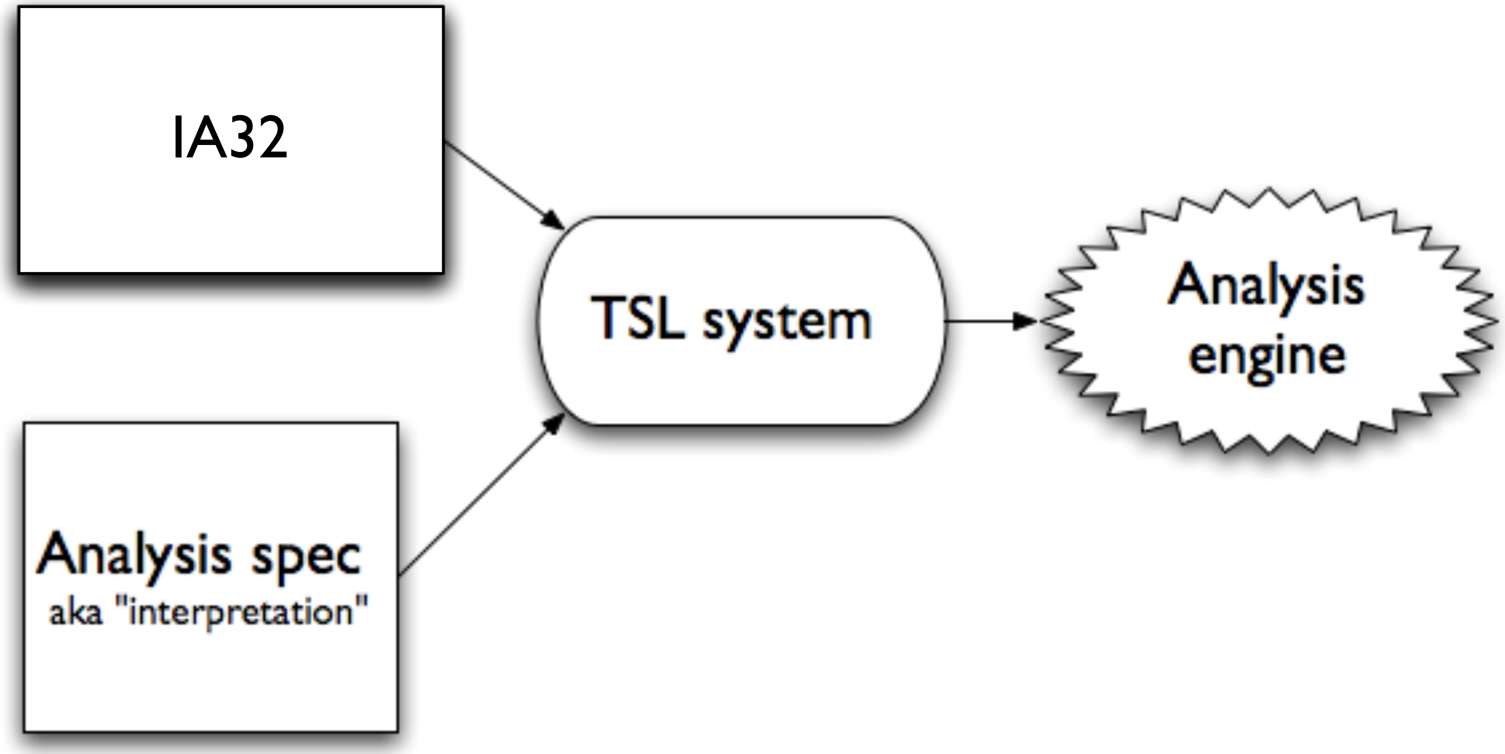
Analysis spec

aka "interpretation"

- TSL (Transformer Specification Language) lets us *generate static analyzers from specifications*. Great!

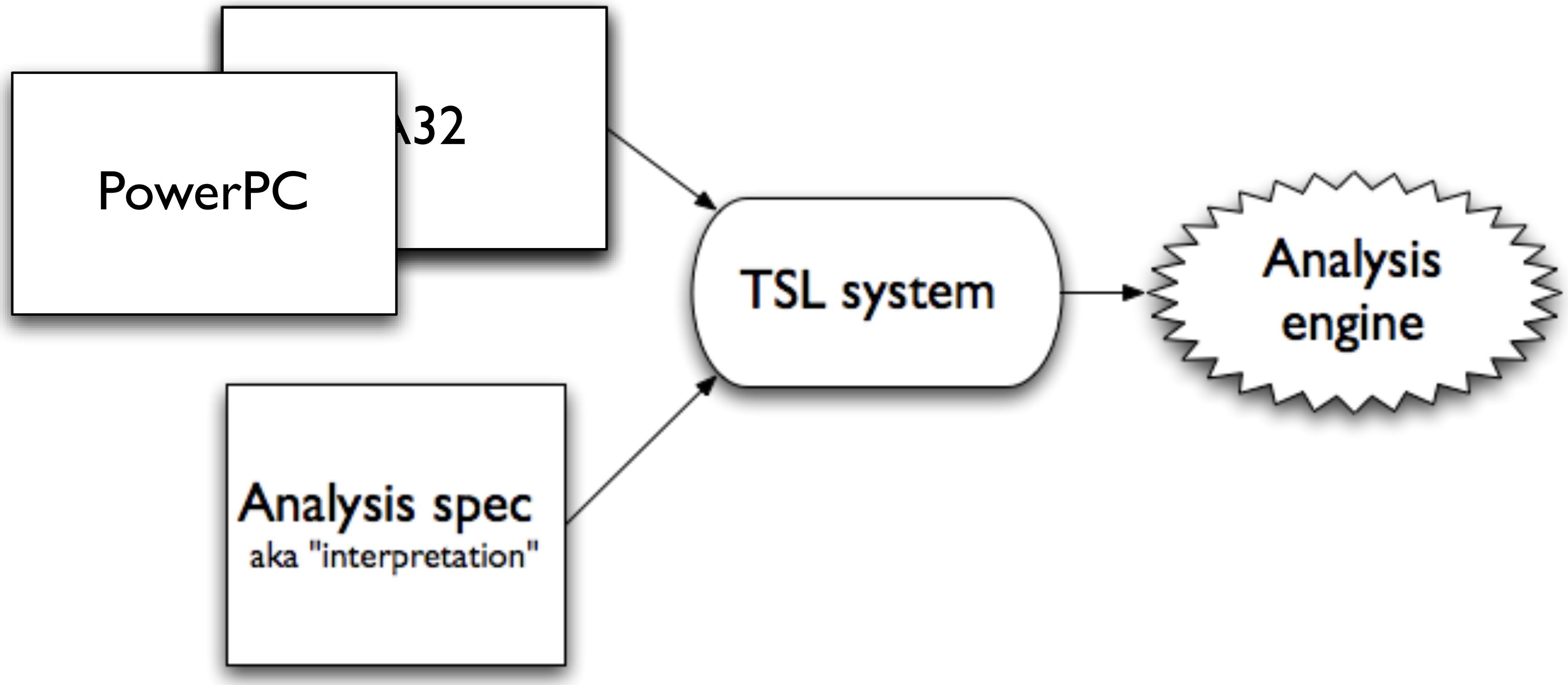
Lim, J, and Reps, T. , "A System for Generating Static Analyzers from Machine Instructions", CC '08

The TSL testing problem



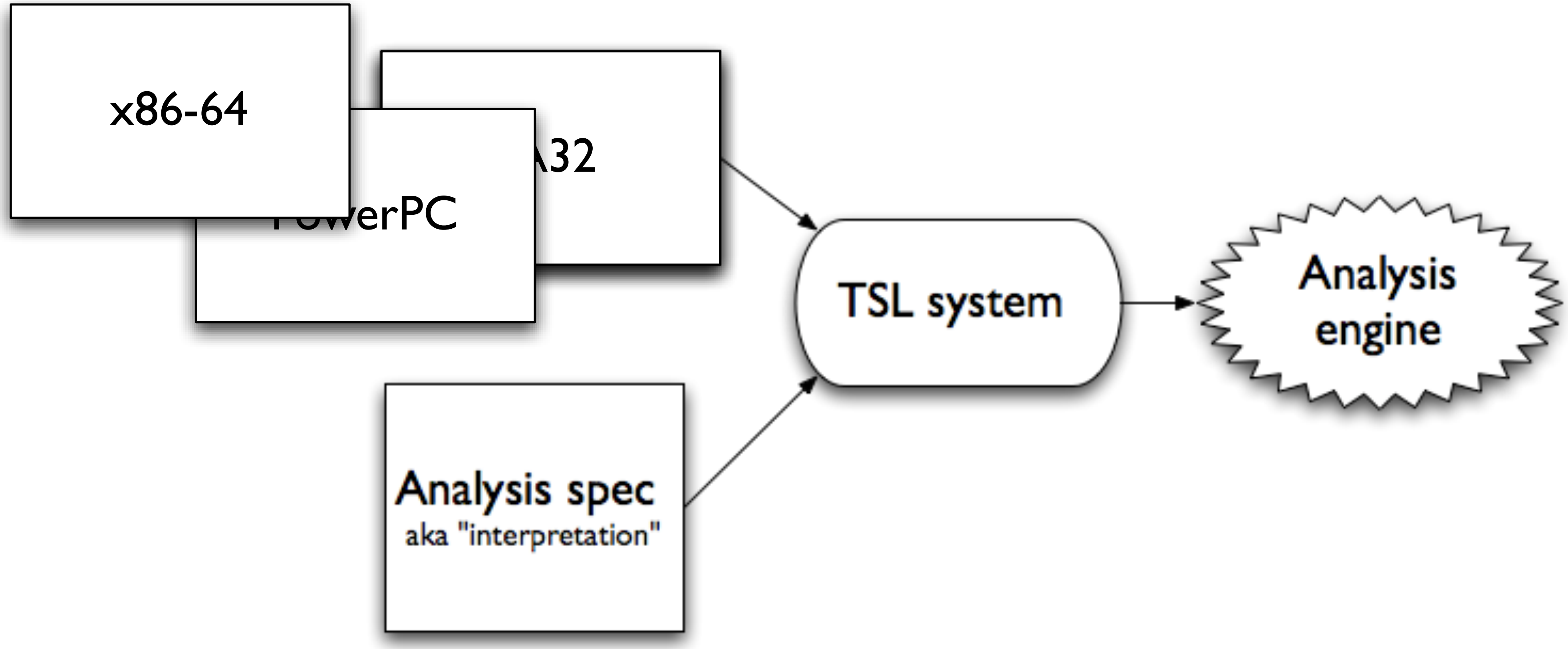
- TSL (Transformer Specification Language) lets us *generate static analyzers from specifications*. Great!

The TSL testing problem



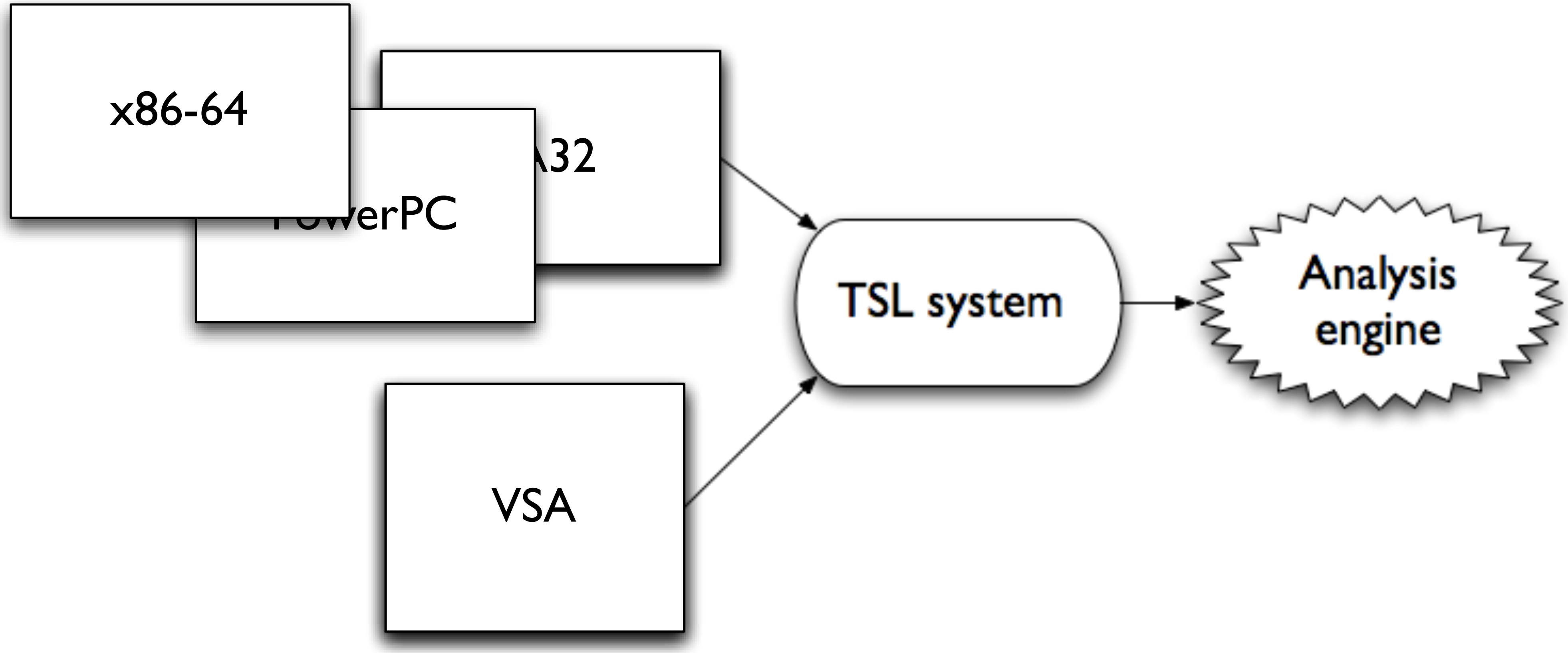
- TSL (Transformer Specification Language) lets us *generate static analyzers from specifications*. Great!

The TSL testing problem



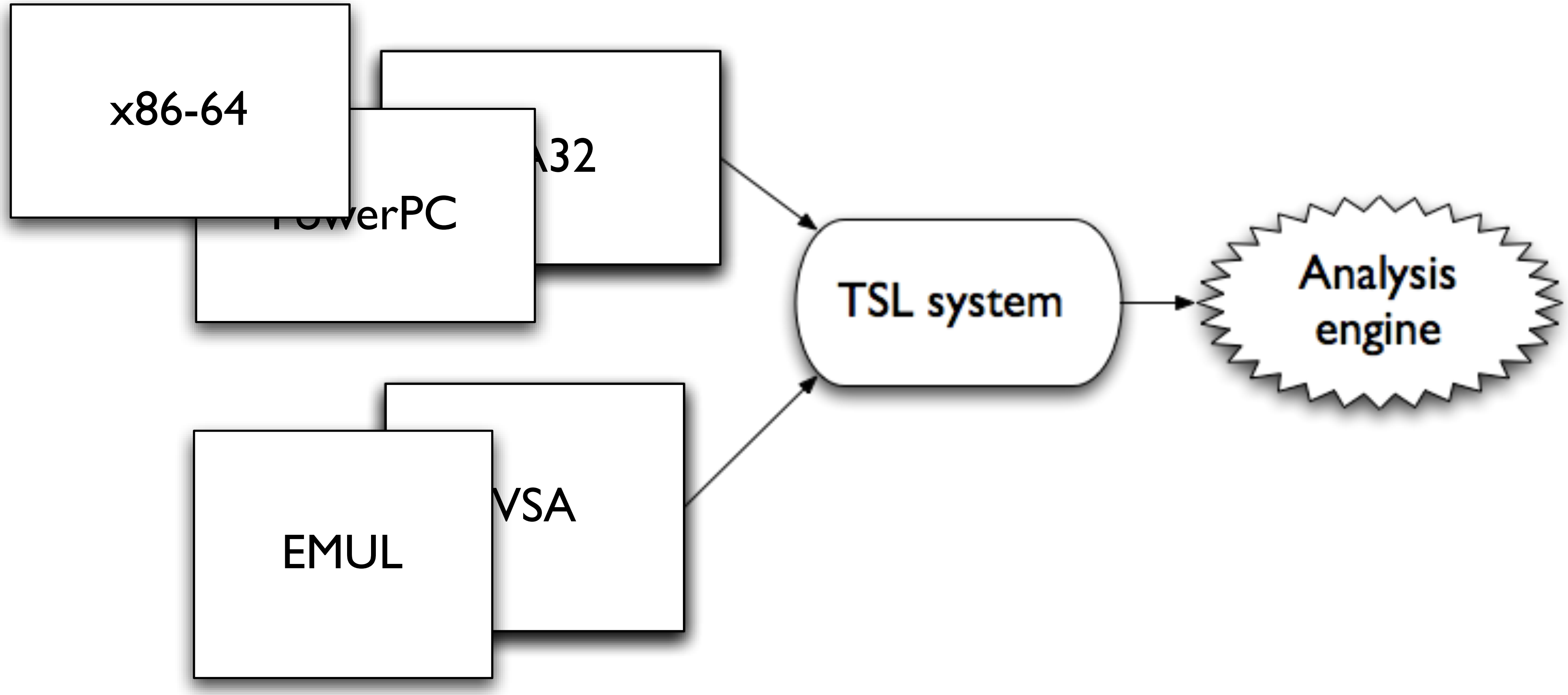
- TSL (Transformer Specification Language) lets us *generate static analyzers from specifications*. Great!

The TSL testing problem



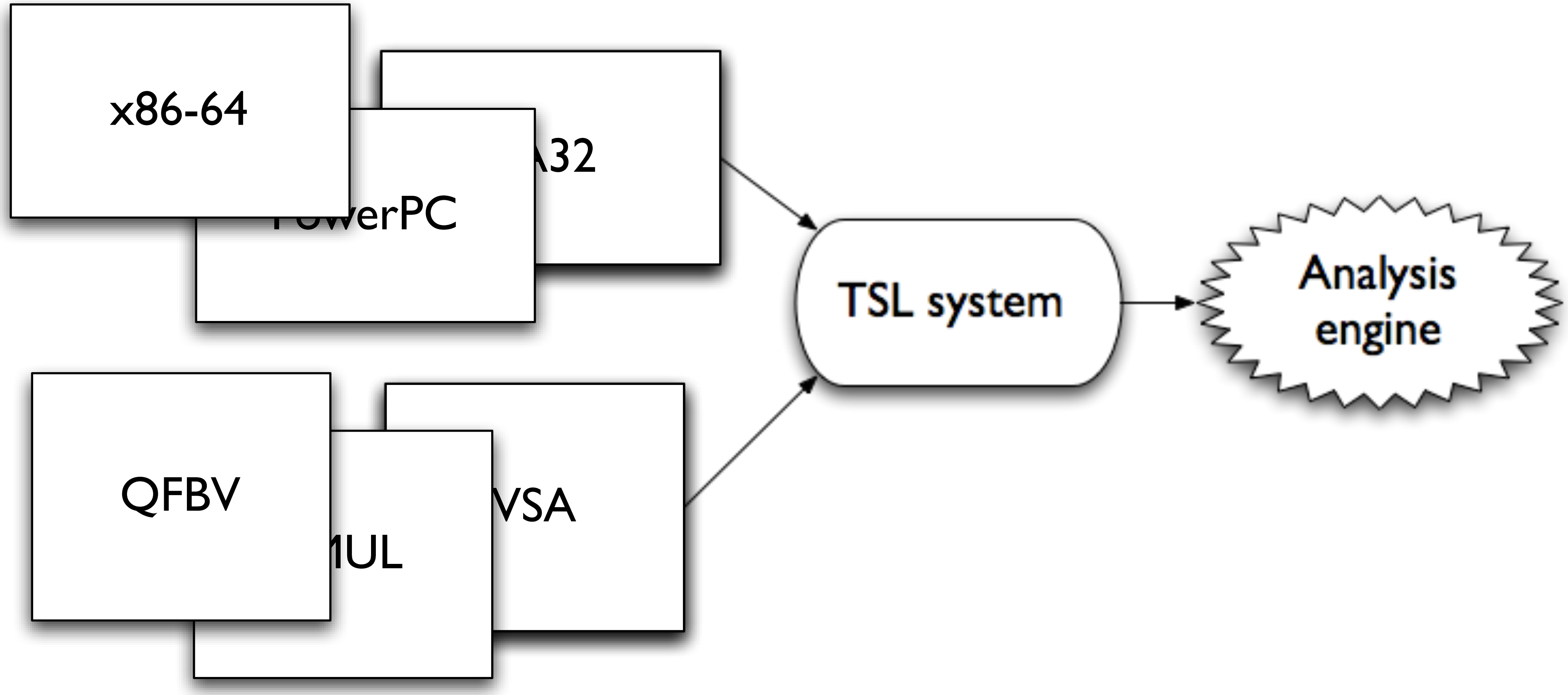
- TSL (Transformer Specification Language) lets us *generate static analyzers from specifications*. Great!

The TSL testing problem



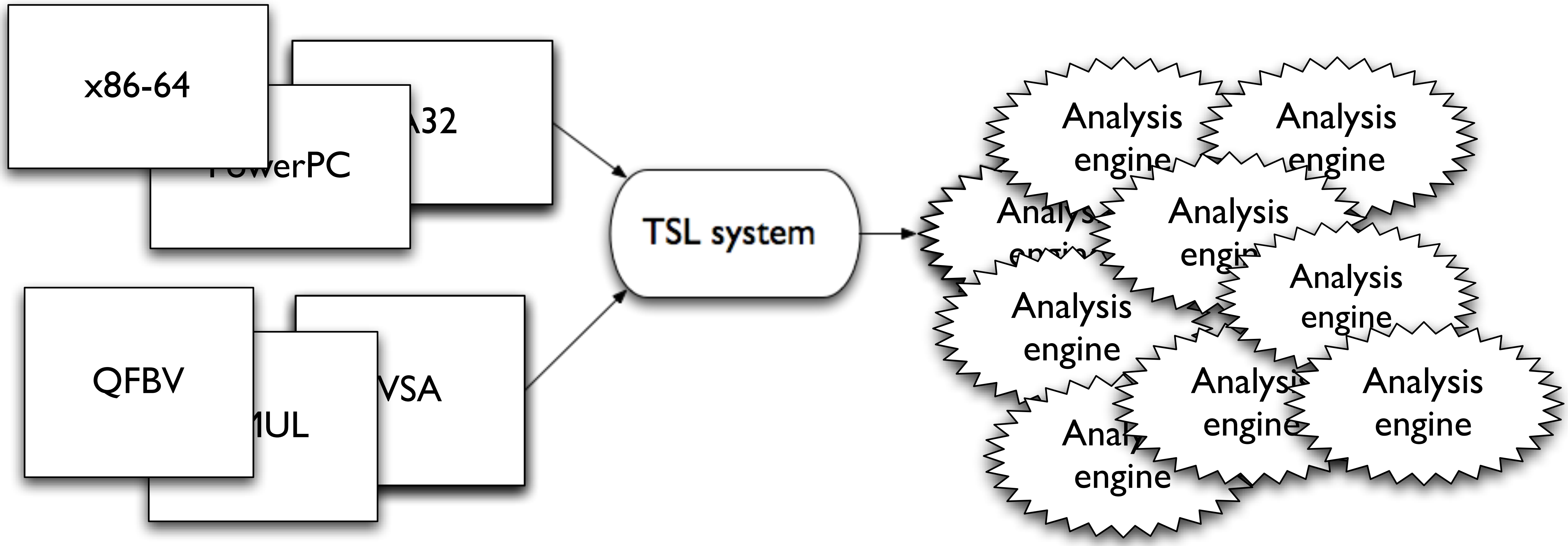
- TSL (Transformer Specification Language) lets us *generate static analyzers from specifications*. Great!

The TSL testing problem



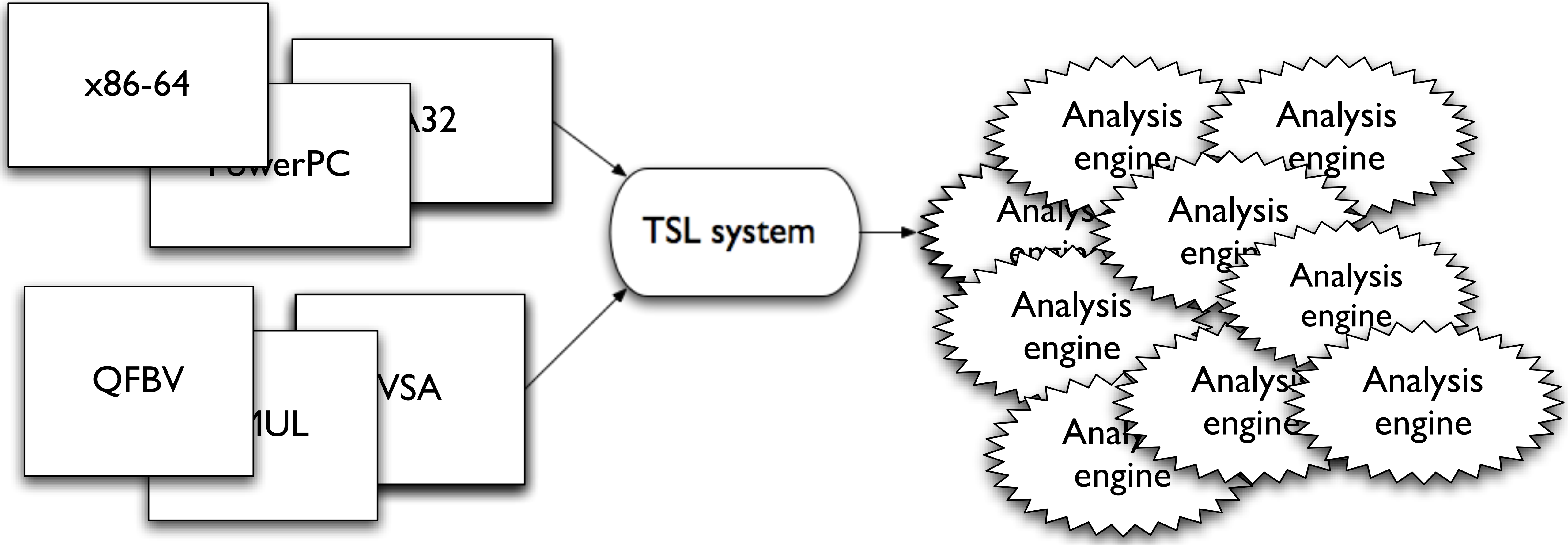
- TSL (Transformer Specification Language) lets us *generate static analyzers from specifications*. Great!

The TSL testing problem



- TSL (Transformer Specification Language) lets us *generate static analyzers from specifications*. Great!

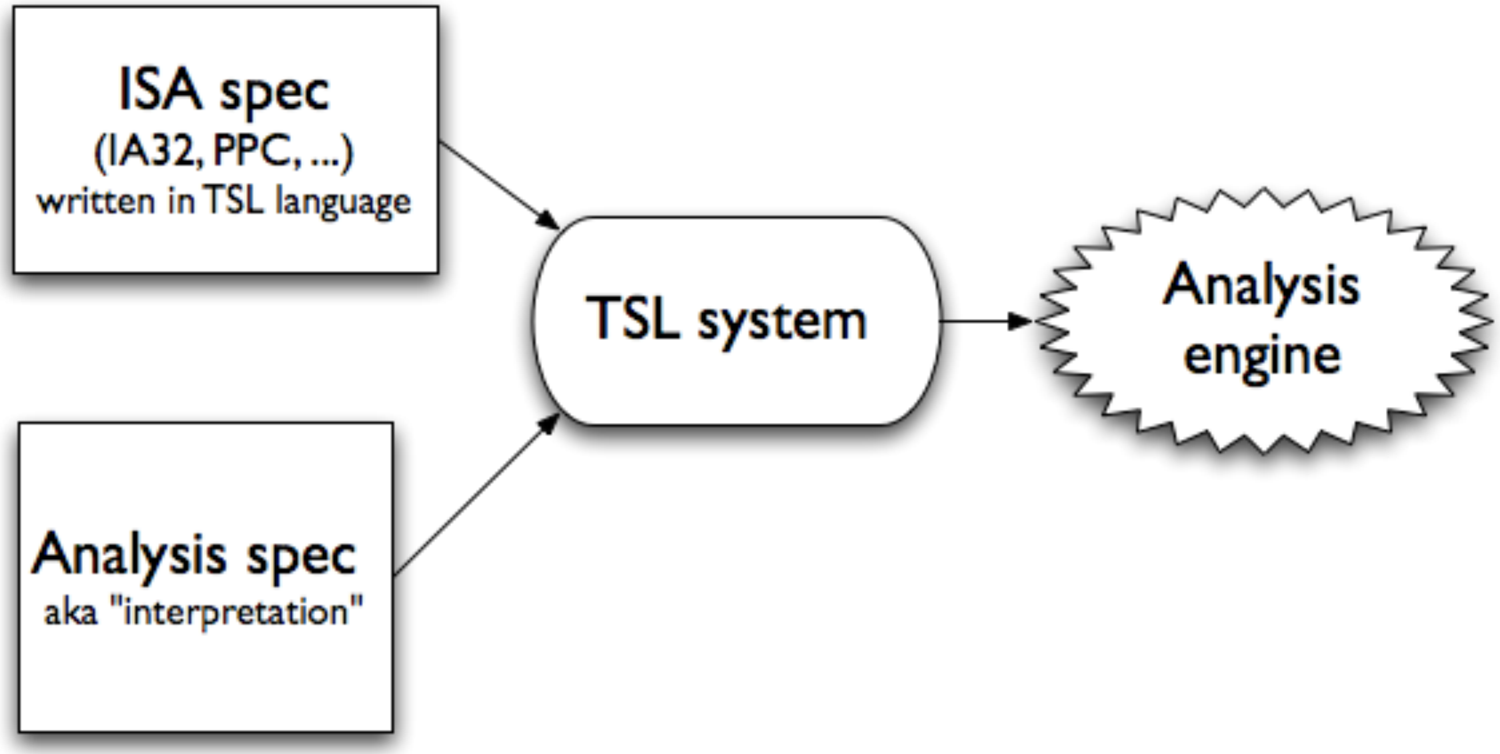
The TSL testing problem



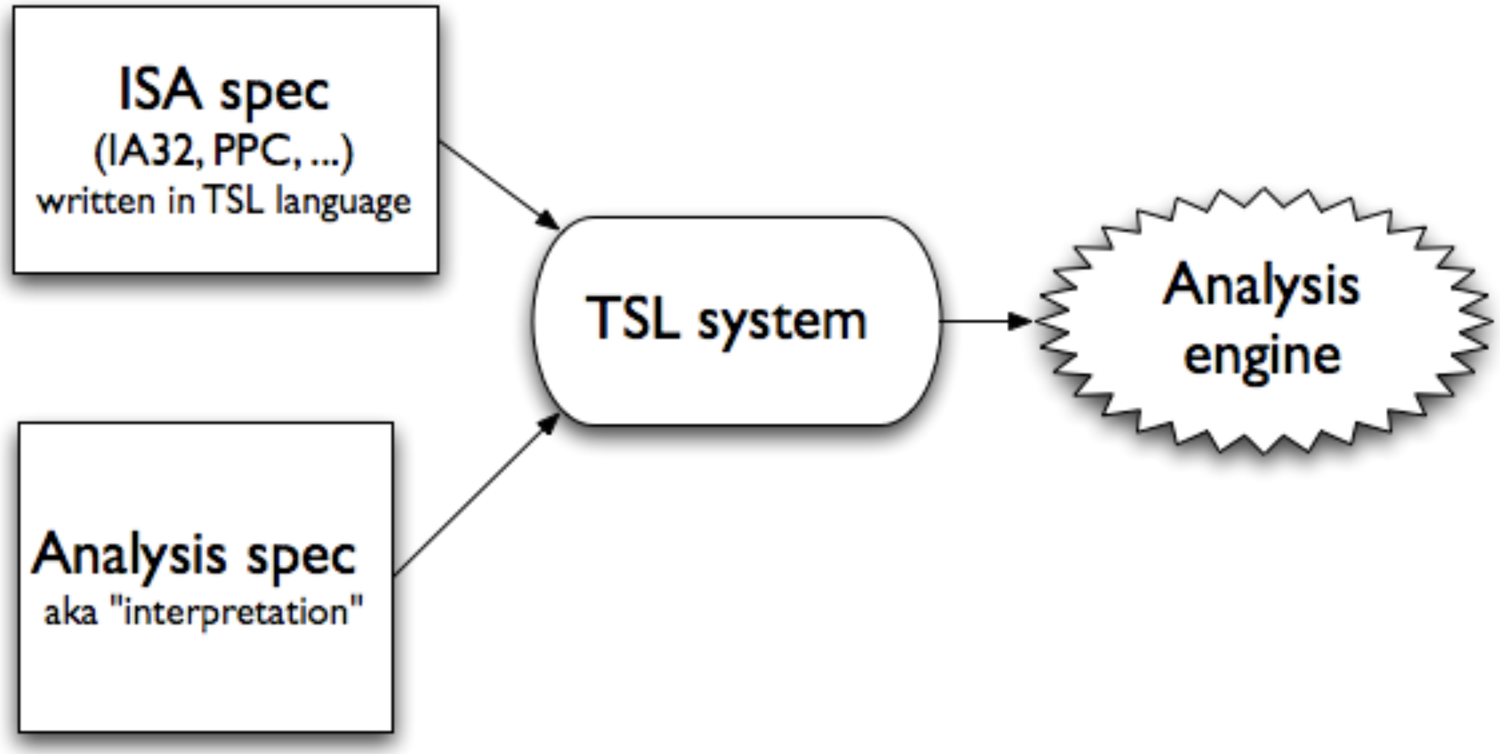
- TSL (Transformer Specification Language) lets us *generate static analyzers from specifications*. Great!
- But how do we know if the generated analysis engines (*multiplicatively many!*) are **correct**?

Our approach

Our approach

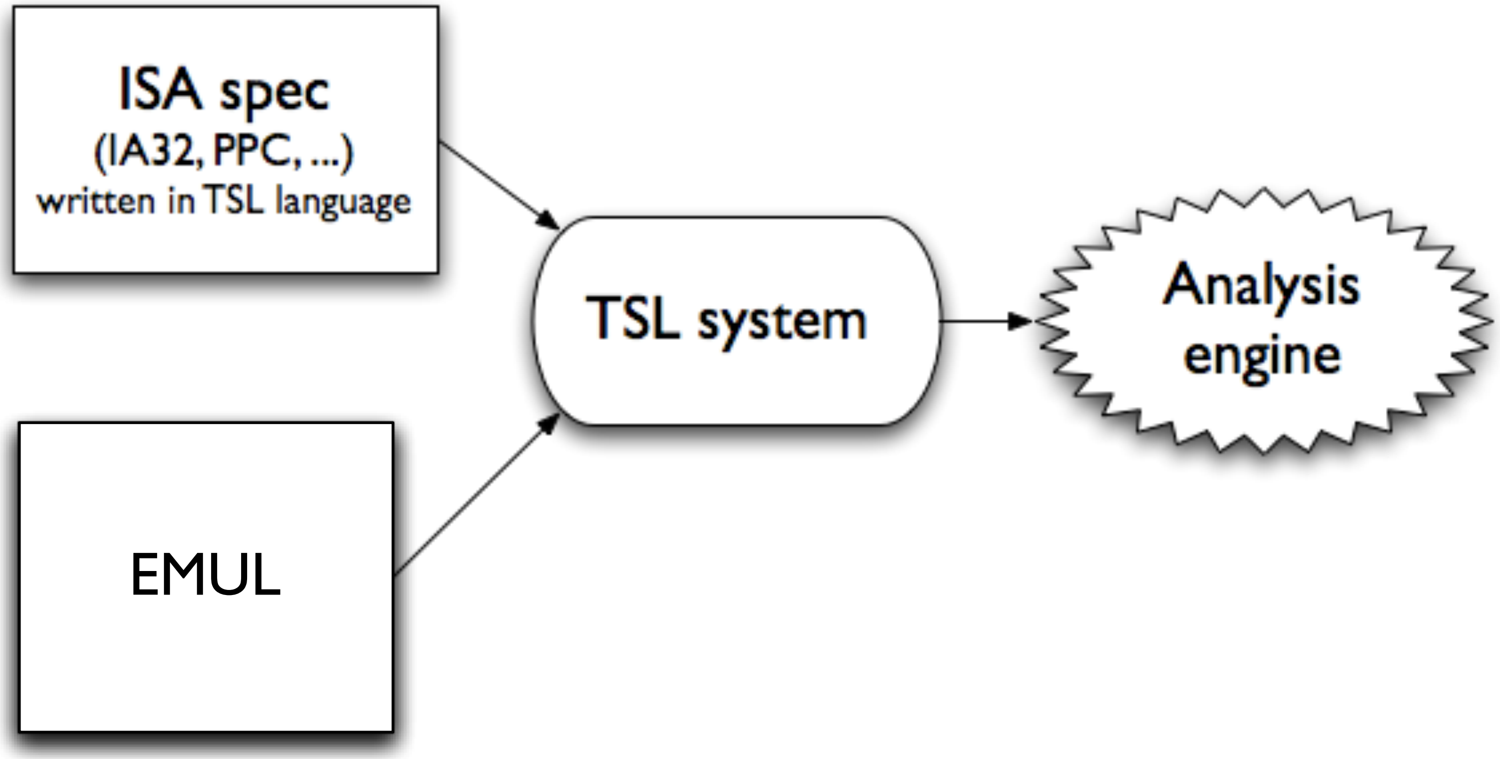


Our approach



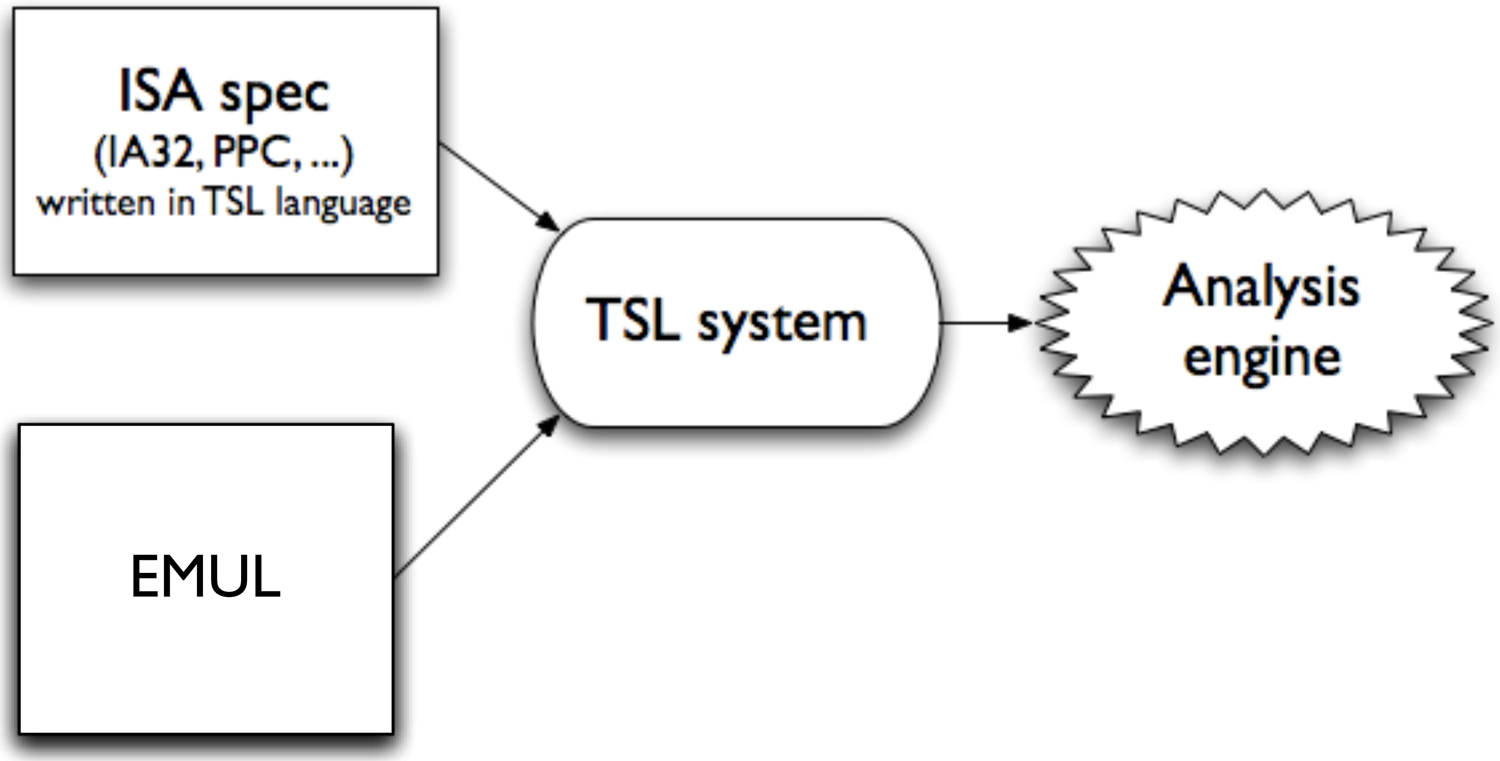
- Narrow the focus to testing just the ISA specs.

Our approach



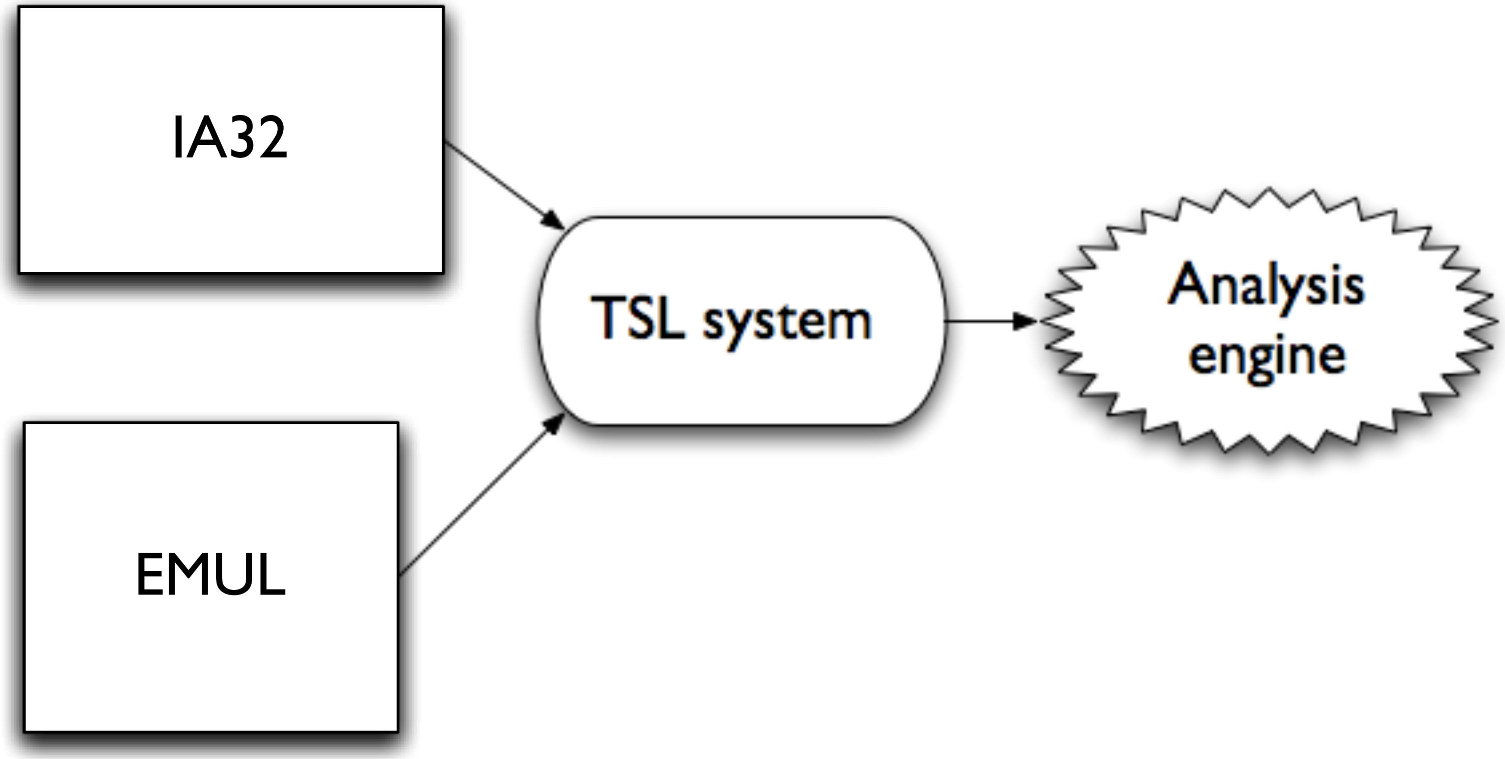
- Narrow the focus to testing just the ISA specs.

Our approach



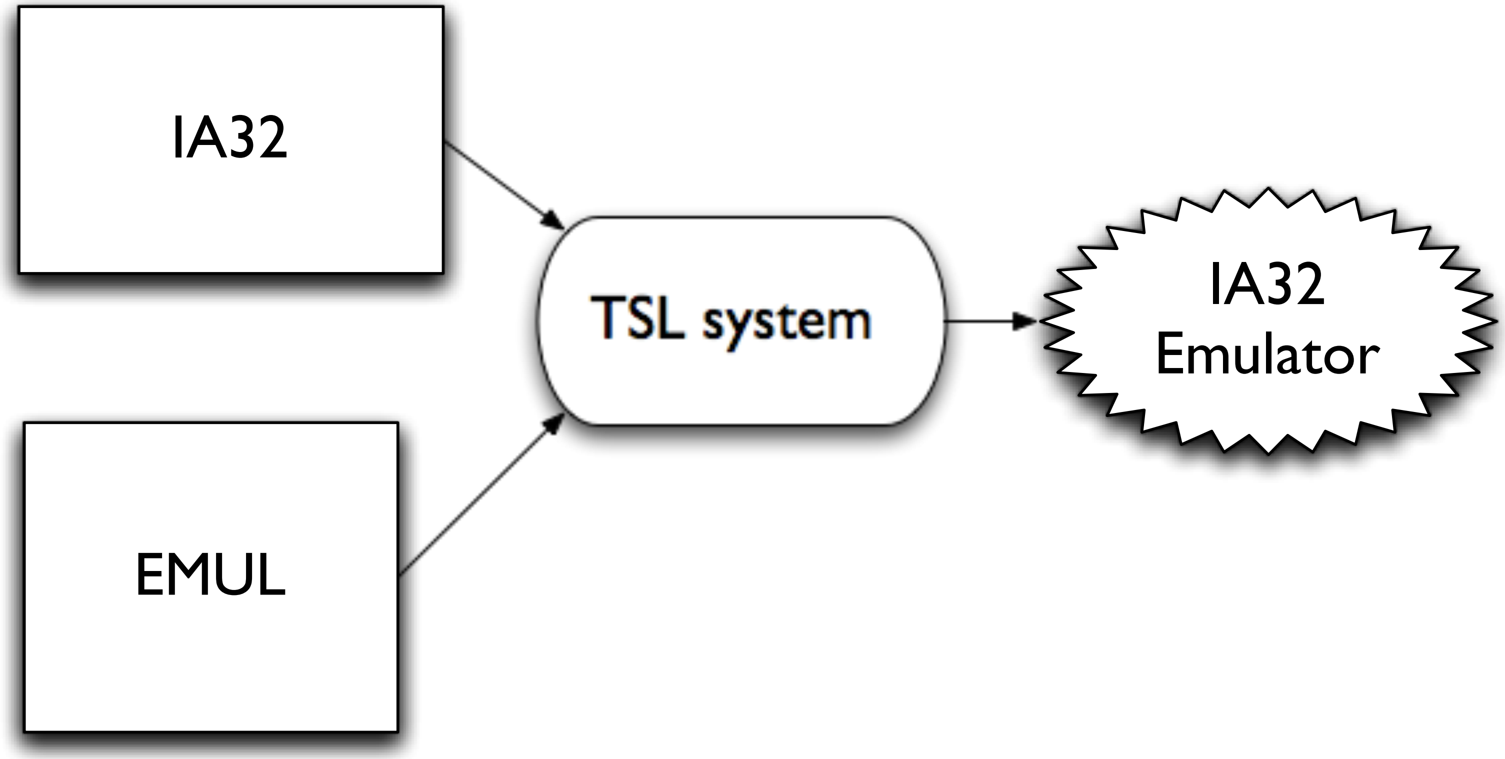
- Narrow the focus to testing just the ISA specs.
- Can we really *isolate* an ISA spec? We can come close by using EMUL, the "simplest" interpretation.

Our approach



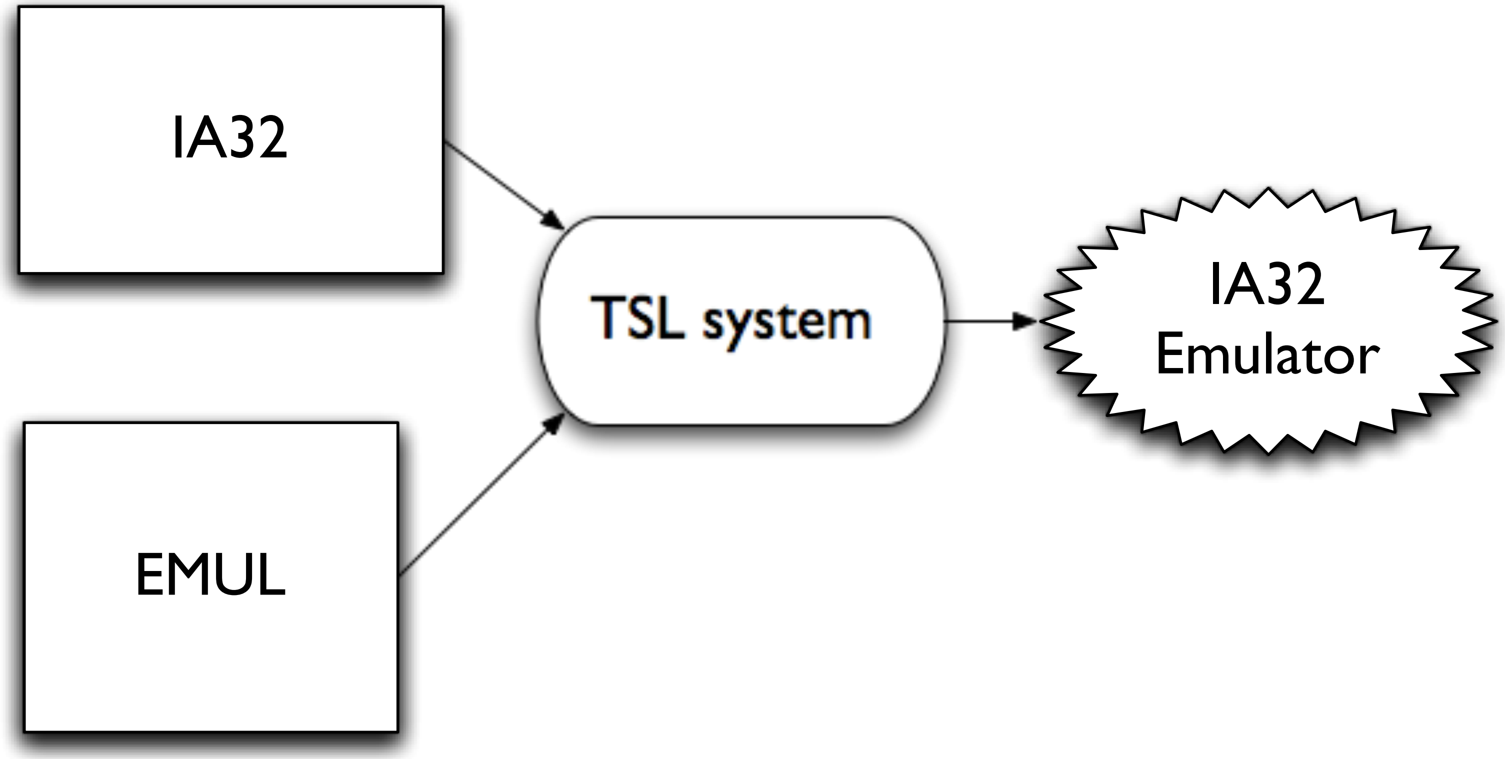
- Narrow the focus to testing just the ISA specs.
- Can we really *isolate* an ISA spec? We can come close by using EMUL, the "simplest" interpretation.

Our approach



- Narrow the focus to testing just the ISA specs.
- Can we really *isolate* an ISA spec? We can come close by using EMUL, the "simplest" interpretation.

Our approach



- Narrow the focus to testing just the ISA specs.
- Can we really *isolate* an ISA spec? We can come close by using EMUL, the "simplest" interpretation.
- And for now, start with IA32.

Goal for the summer

Goal for the summer

- **Find out how complete and precise our IA32 TSL specification is...**

Goal for the summer

- **Find out how complete and precise our IA32 TSL specification is...**
  - ...by generating an IA32 emulator, then comparing the emulator to the real processor.

Goal for the summer

- **Find out how complete and precise our IA32 TSL specification is...**
  - ...by generating an IA32 emulator, then comparing the emulator to the real processor.
  - If resulting states differ on the same inputs, the spec was (*probably)* buggy.

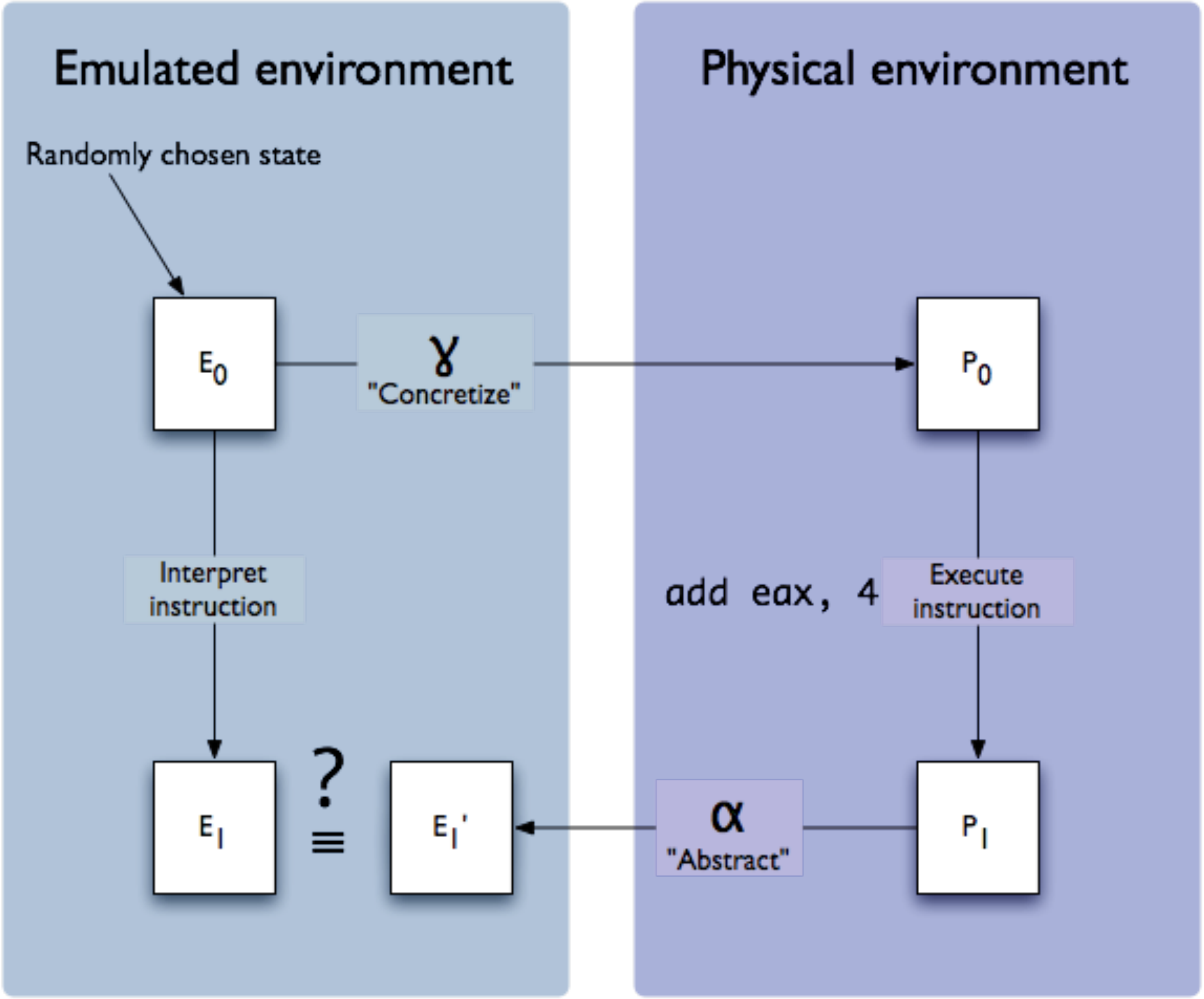
Goal for the summer

- **Find out how complete and precise our IA32 TSL specification is...**
  - ...by generating an IA32 emulator, then comparing the emulator to the real processor.
  - If resulting states differ on the same inputs, the spec was (*probably*) buggy.
- *We already have all the pieces*: IA32 spec, EMUL, and a third-party tool for testing CPU emulators. This will be easy, right?!

How to test a CPU emulator

How to test a CPU emulator

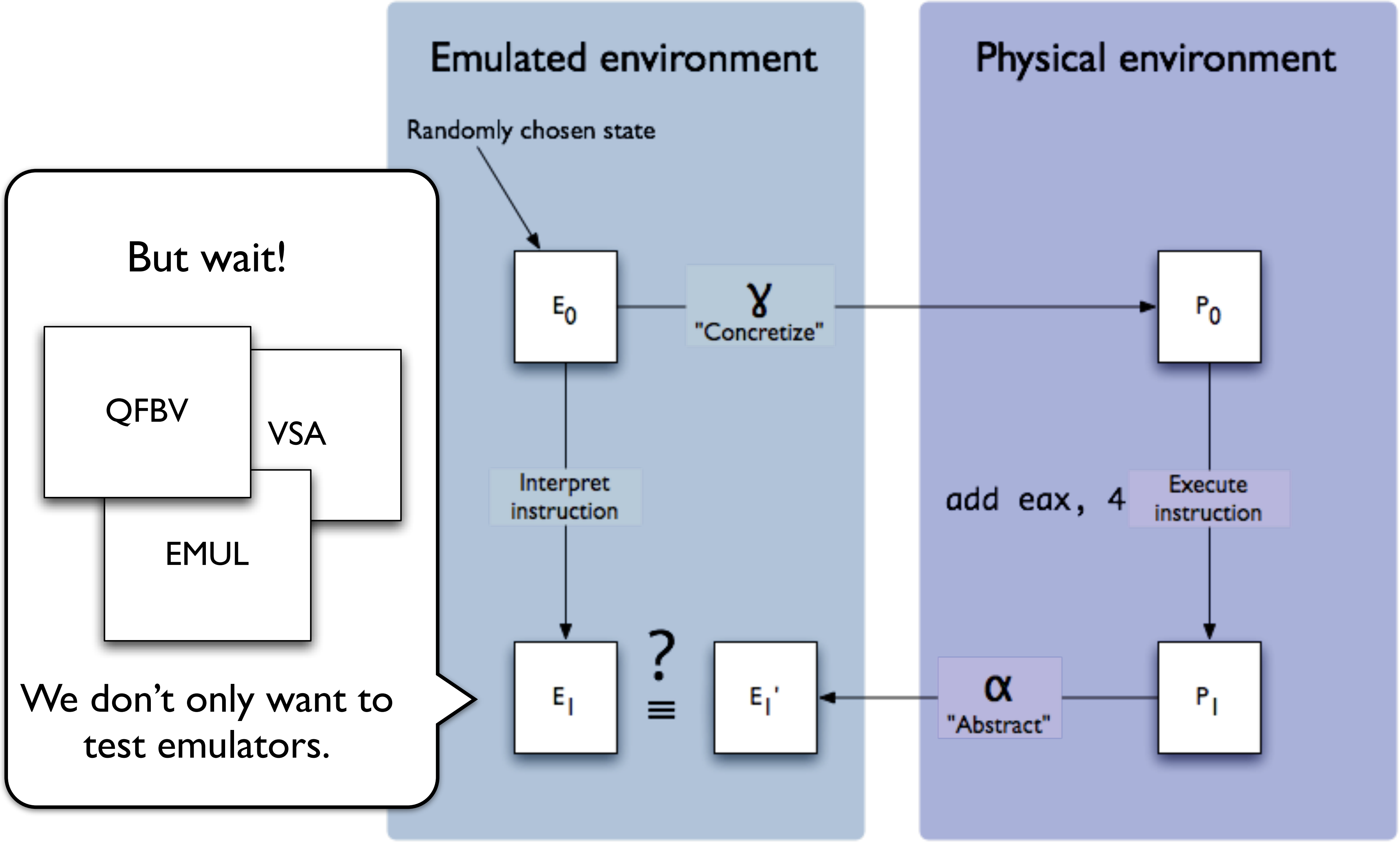
EmuFuzzer's design



Martignioni, L., et al, "Testing CPU Emulators", ISSTA '09

How to test a CPU emulator

EmuFuzzer's design



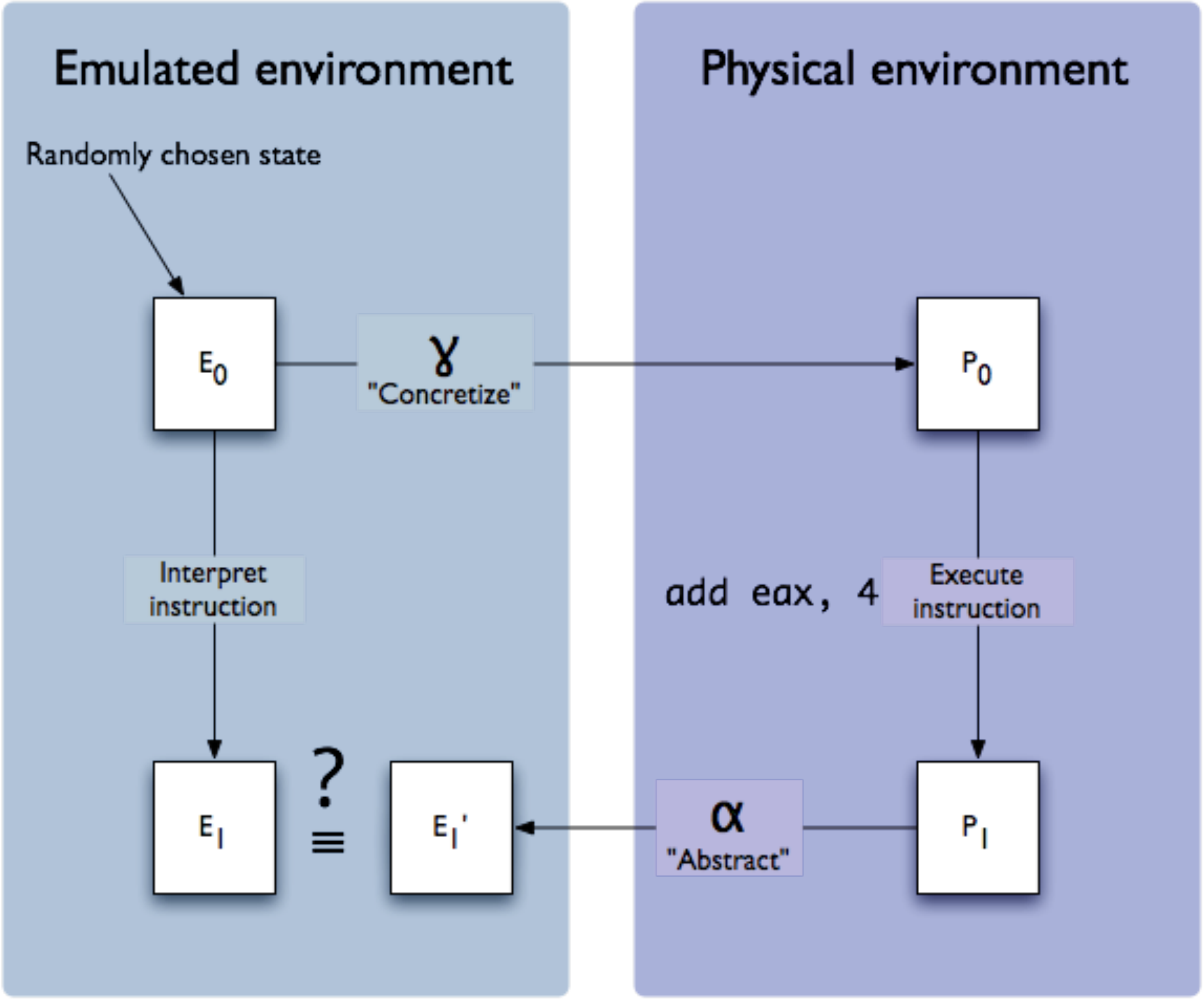
But wait!

We don't only want to test emulators.

Martignioni, L., et al, "Testing CPU Emulators", ISSTA '09

How to test a CPU emulator

EmuFuzzer's design



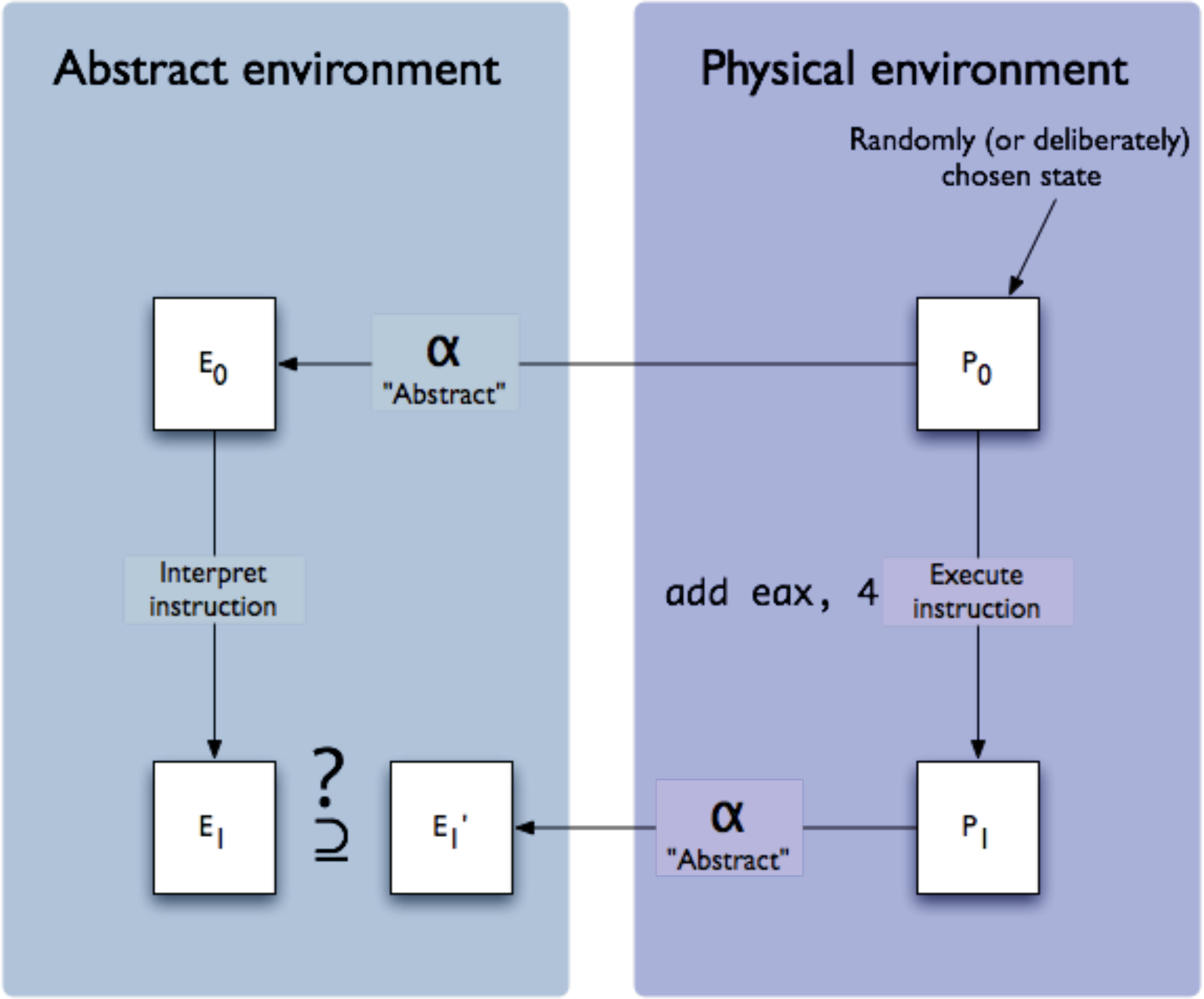
Martignioni, L., et al, "Testing CPU Emulators", ISSTA '09

How to test a CPU emulator

How to (someday) test any analysis engine

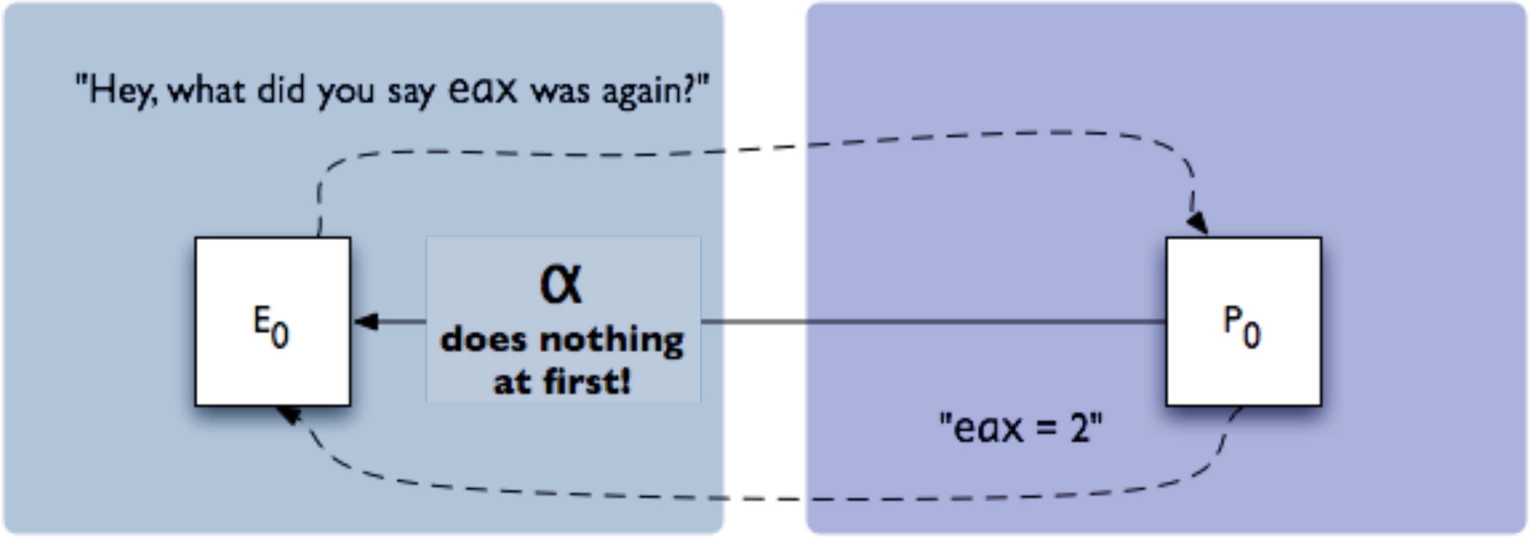
How to (someday) test any analysis engine

Our design

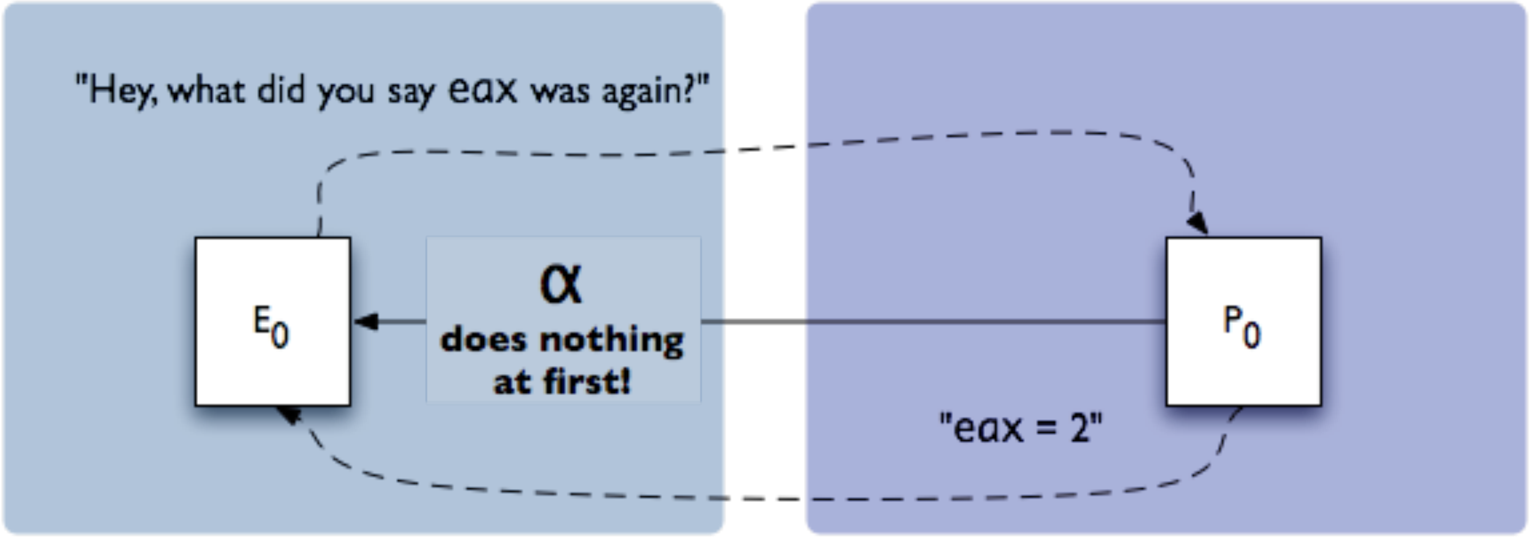


Look-thru memory

Look-thru memory



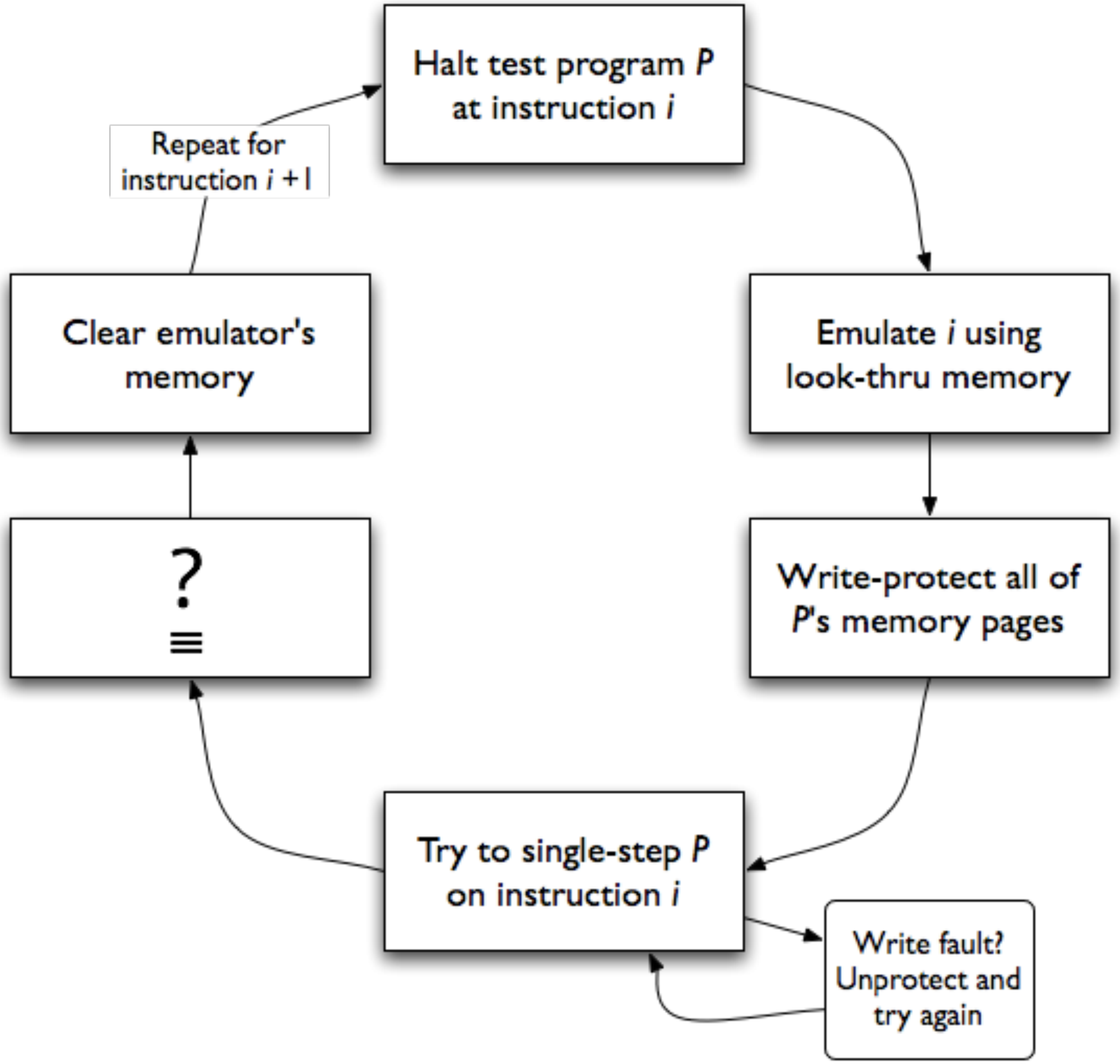
Look-thru memory



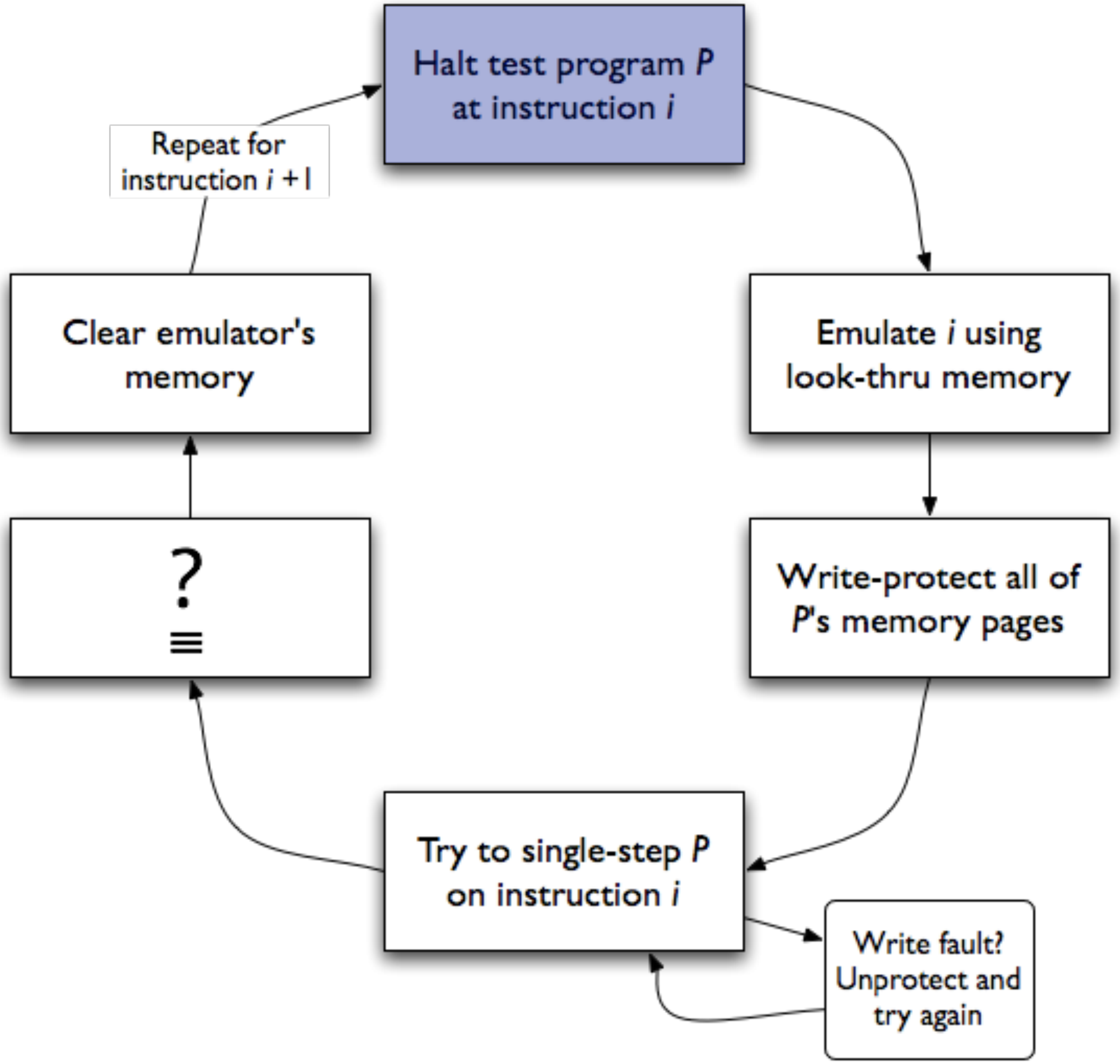
- The ability to *lazily* instantiate the emulator's state (memory and registers) from that of the process as each instruction is being emulated.

TSL validator main loop

TSL validator main loop

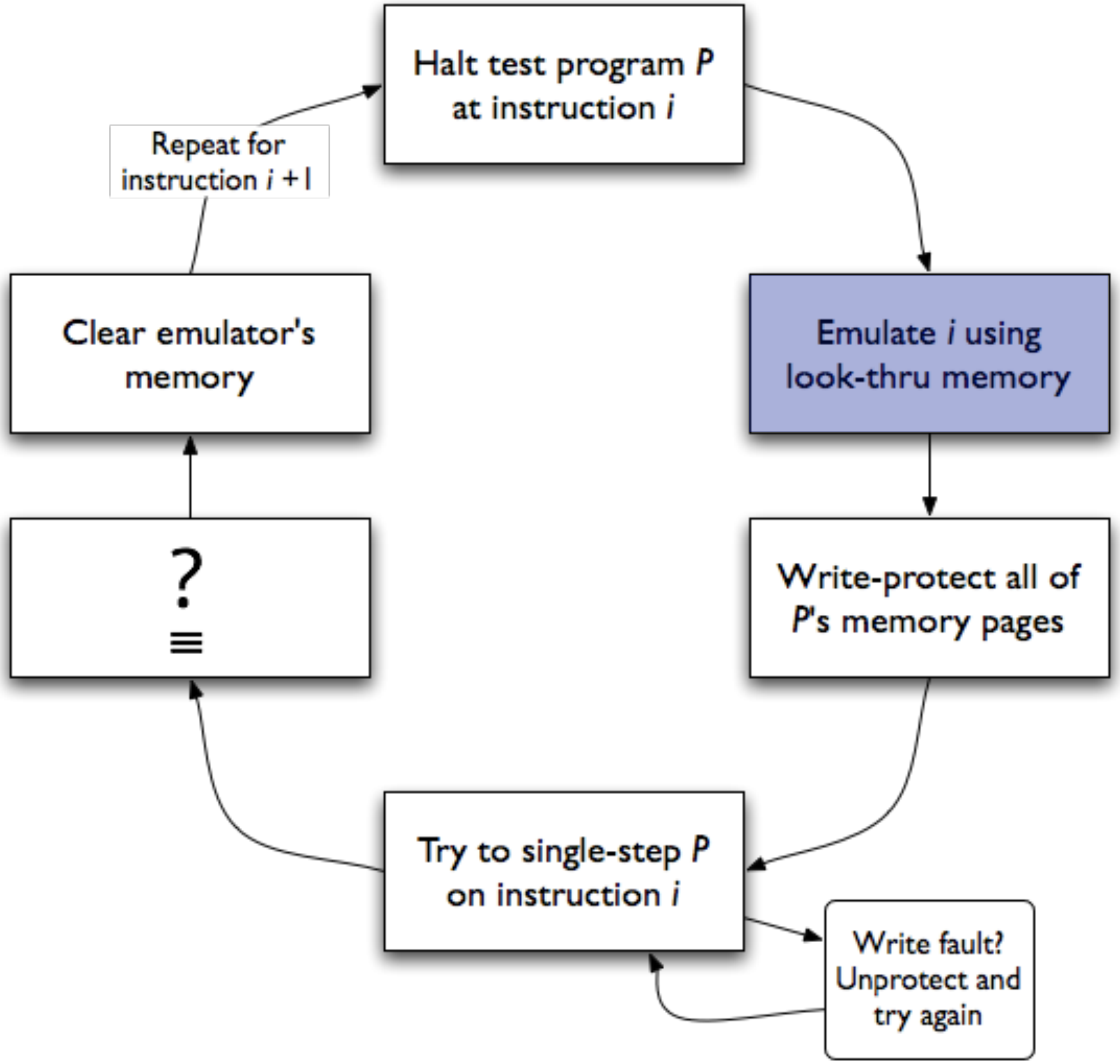

Halt test program *P* at instruction *i*
Emulate *i* using look-thru memory
Write-protect all of *P*'s memory pages
Try to single-step *P* on instruction *i*
Write fault? Unprotect and try again
?
≡
Clear emulator's memory
Repeat for instruction *i* +1

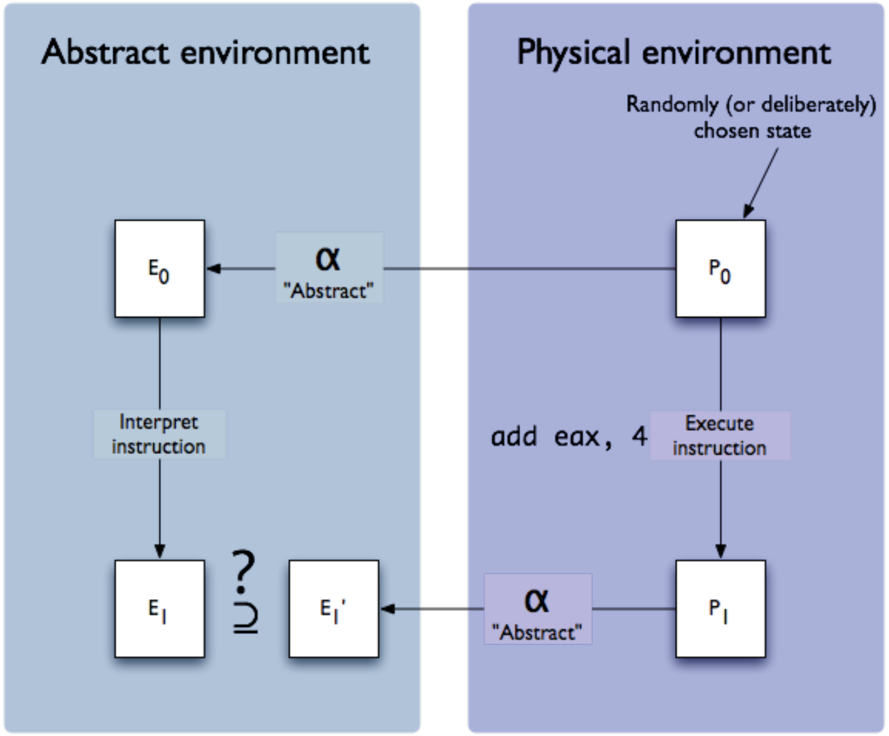
TSL validator main loop



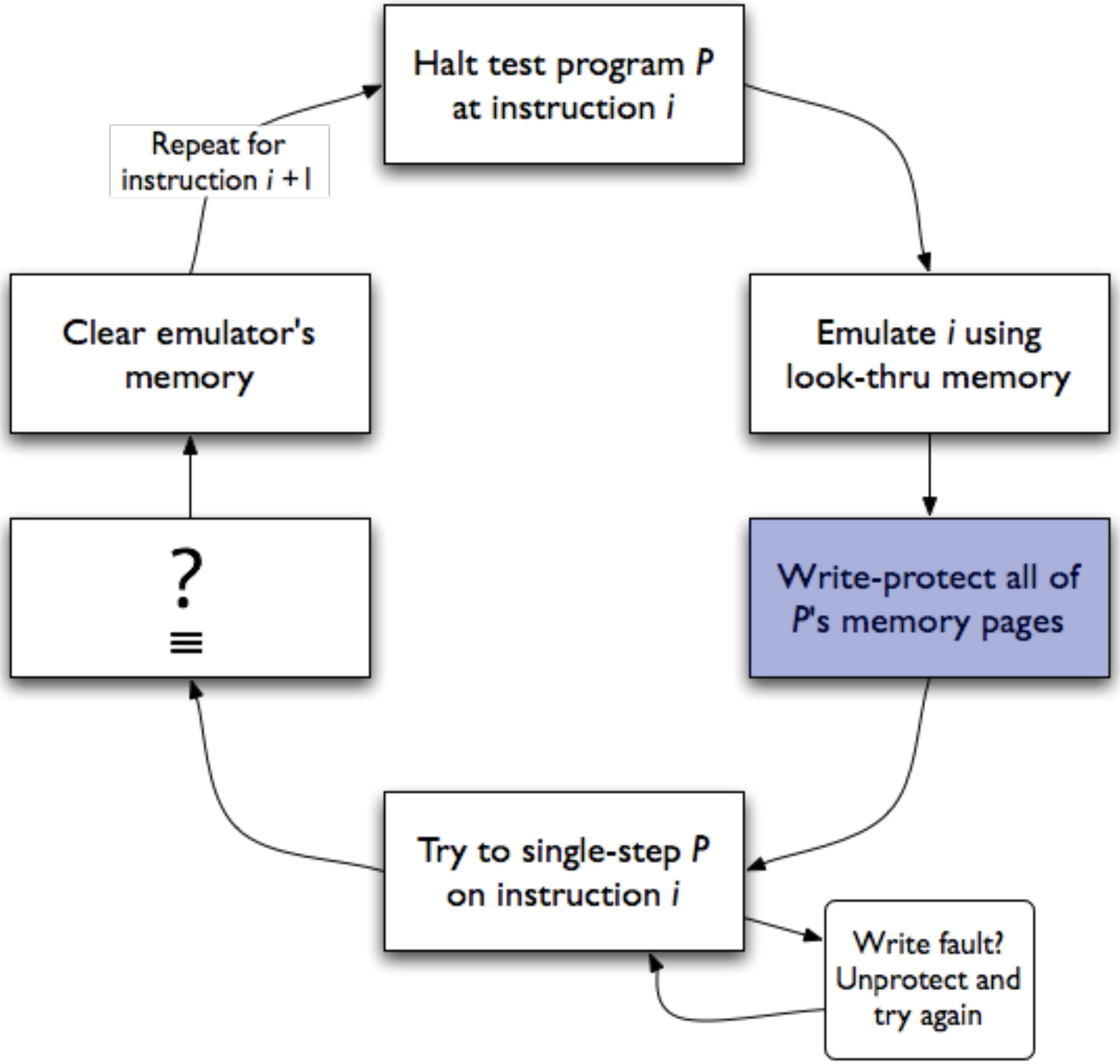
Halt test program *P* at instruction *i*
Emulate *i* using look-thru memory
Write-protect all of *P*'s memory pages
Try to single-step *P* on instruction *i*
Write fault? Unprotect and try again
?
≡
Clear emulator's memory
Repeat for instruction *i* +1

TSL validator main loop


Halt test program *P* at instruction *i*
Emulate *i* using look-thru memory
Write-protect all of *P*'s memory pages
Try to single-step *P* on instruction *i*
Write fault? Unprotect and try again
?
≡
Clear emulator's memory
Repeat for instruction *i* +1



TSL validator main loop



Halt test program *P* at instruction *i*

Emulate *i* using look-thru memory

Write-protect all of *P*'s memory pages

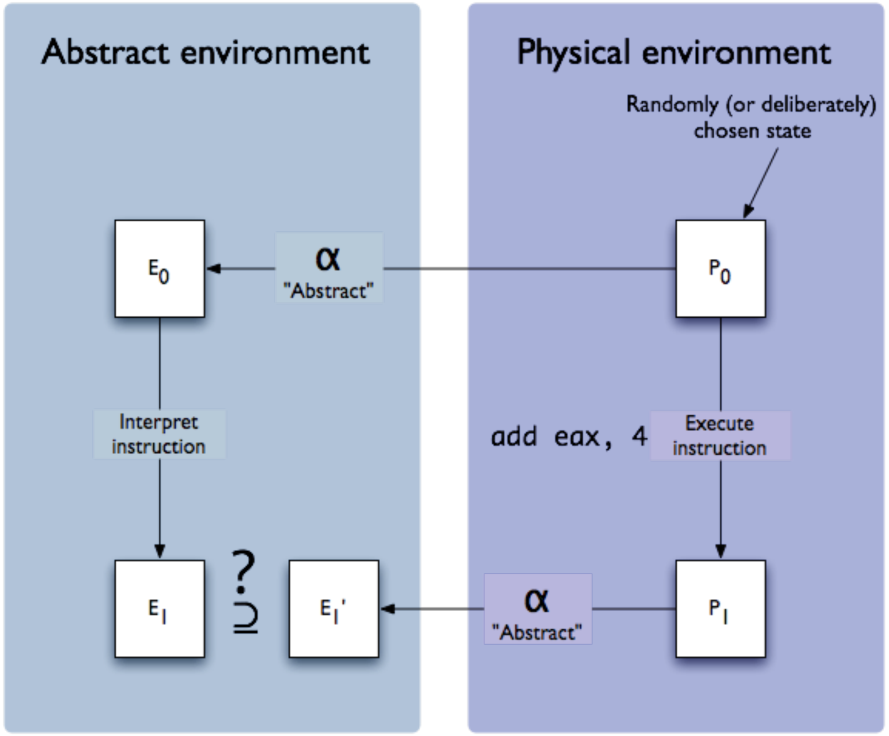
Try to single-step *P* on instruction *i*

Write fault? Unprotect and try again

$\overset{?}{\equiv}$

Clear emulator's memory

Repeat for instruction *i* +1



Abstract environment

Physical environment

Randomly (or deliberately) chosen state

E_0

α "Abstract"

P_0

Interpret instruction

`add eax, 4`

Execute instruction

E_1

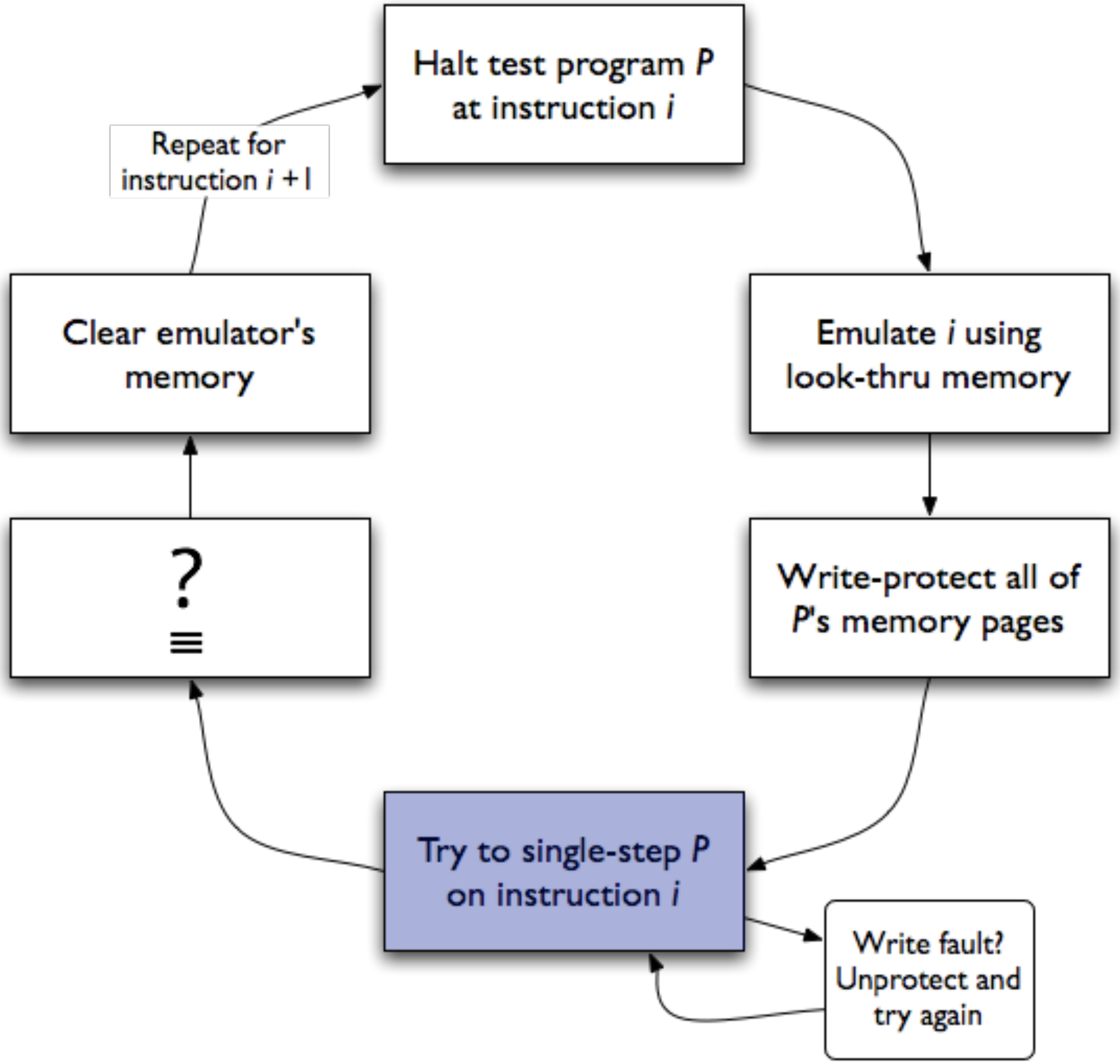
$\overset{?}{\supseteq}$

E_1'

α "Abstract"

P_1

TSL validator main loop



Halt test program *P* at instruction *i*

Emulate *i* using look-thru memory

Write-protect all of *P*'s memory pages

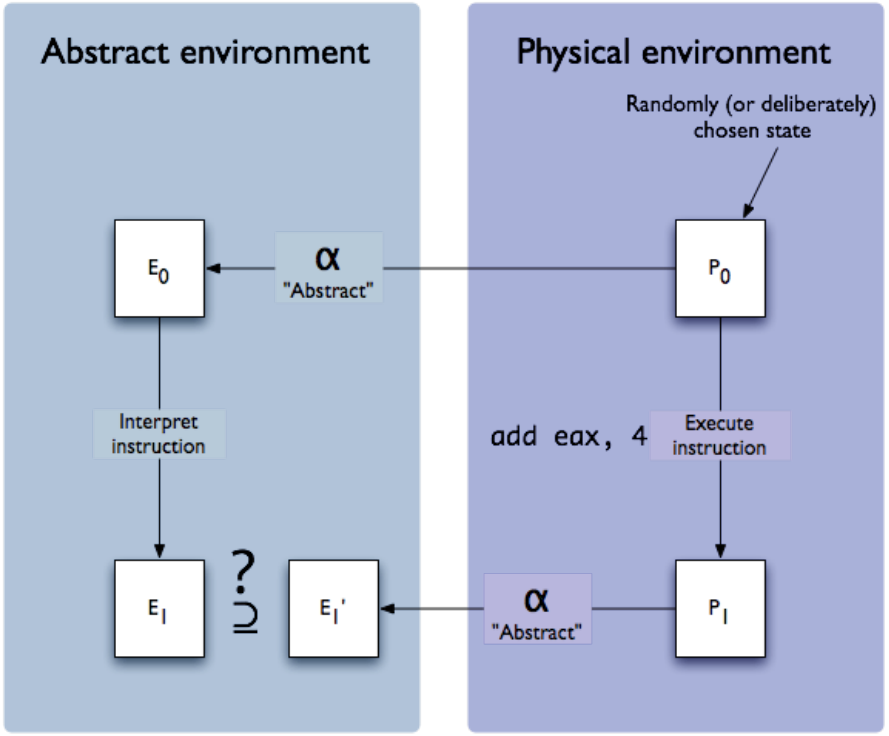
Try to single-step *P* on instruction *i*

Write fault? Unprotect and try again

?
≡

Clear emulator's memory

Repeat for instruction *i* +1



Abstract environment

Physical environment

Randomly (or deliberately) chosen state

E_0

α "Abstract"

P_0

Interpret instruction

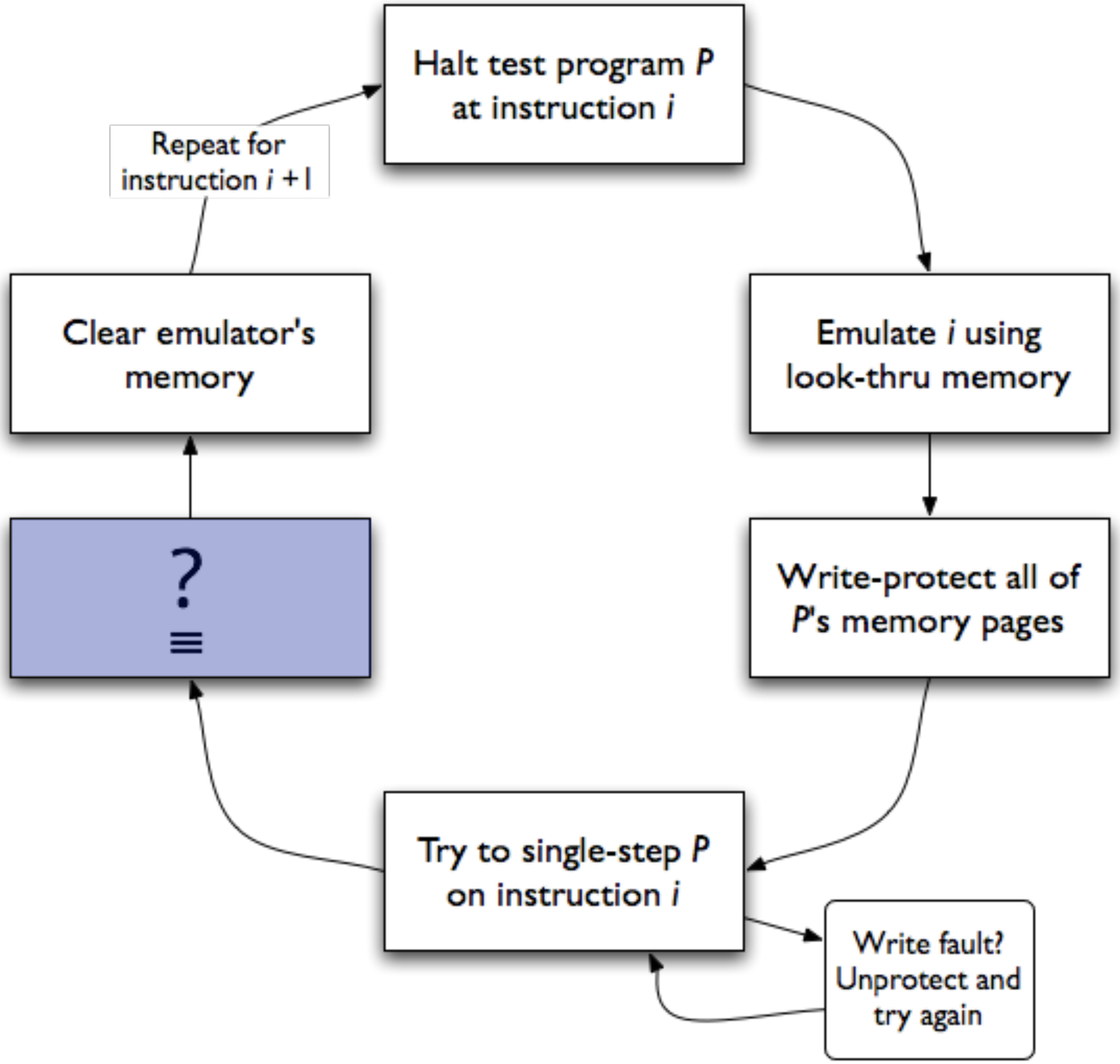
`add eax, 4` Execute instruction

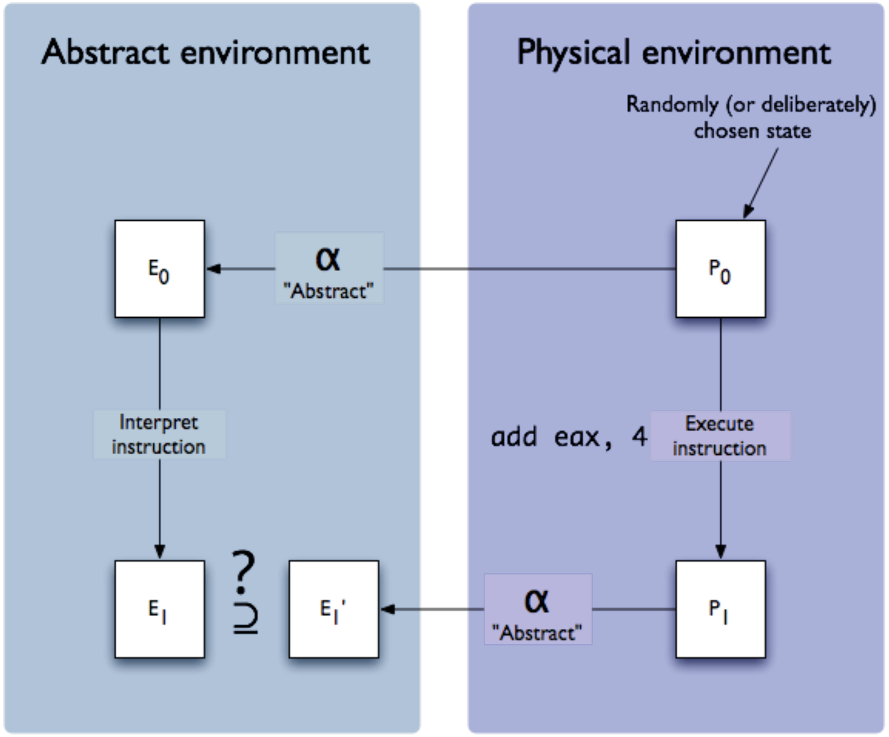
E_1 $\overset{?}{\supseteq}$ E_1'

α "Abstract"

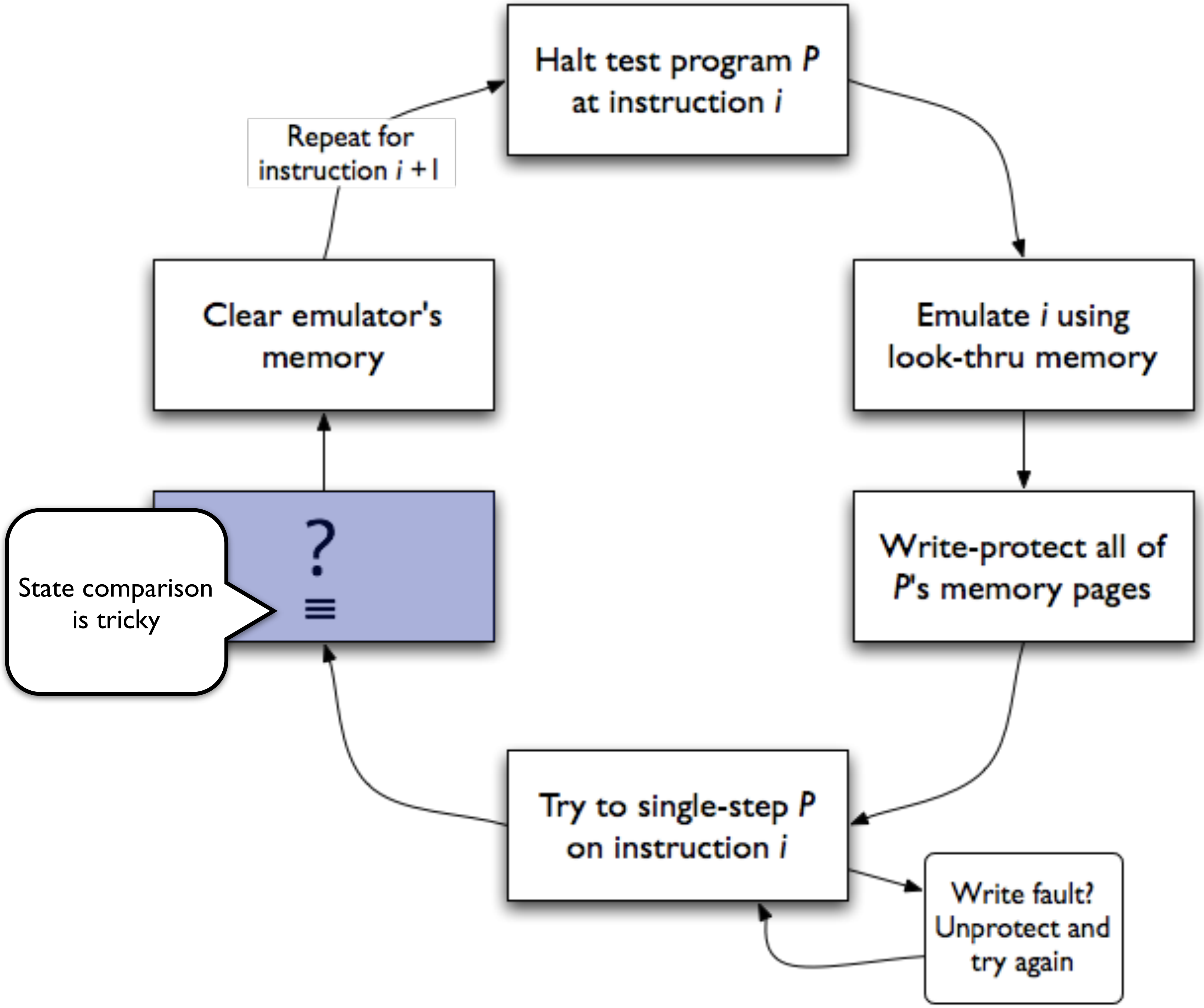
P_1

TSL validator main loop


Halt test program P at instruction i
Emulate i using look-thru memory
Write-protect all of P's memory pages
Try to single-step P on instruction i
Write fault? Unprotect and try again
?
≡
Clear emulator's memory
Repeat for instruction i +1



TSL validator main loop



Halt test program *P* at instruction *i*

Emulate *i* using look-thru memory

Write-protect all of *P*'s memory pages

Try to single-step *P* on instruction *i*

Write fault? Unprotect and try again

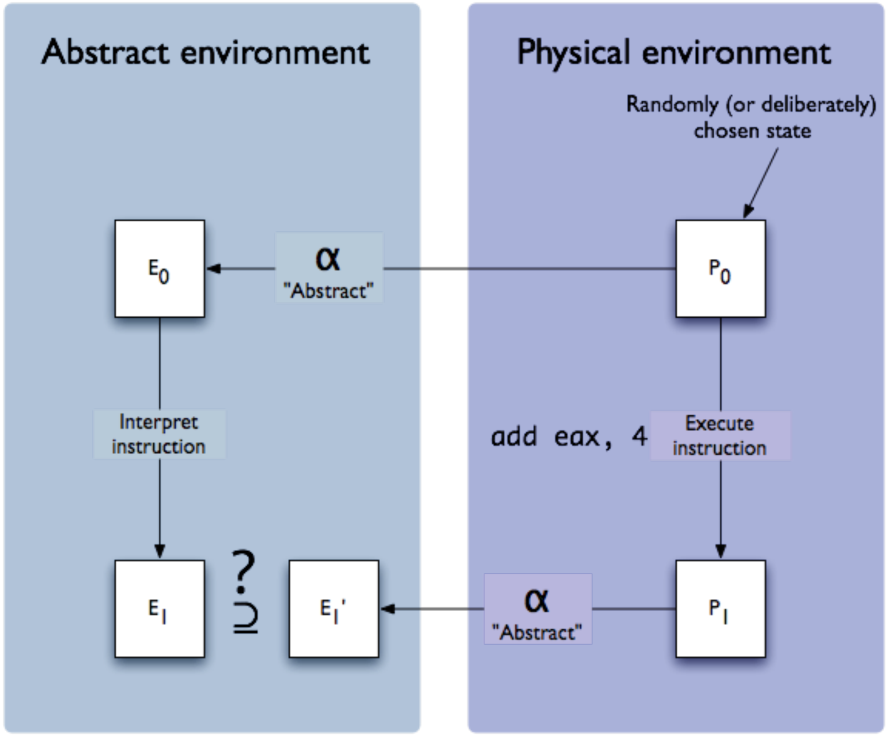
?

≡

State comparison is tricky

Clear emulator's memory

Repeat for instruction *i* +1



Abstract environment

Physical environment

Randomly (or deliberately) chosen state

E_0

α "Abstract"

P_0

Interpret instruction

`add eax, 4`

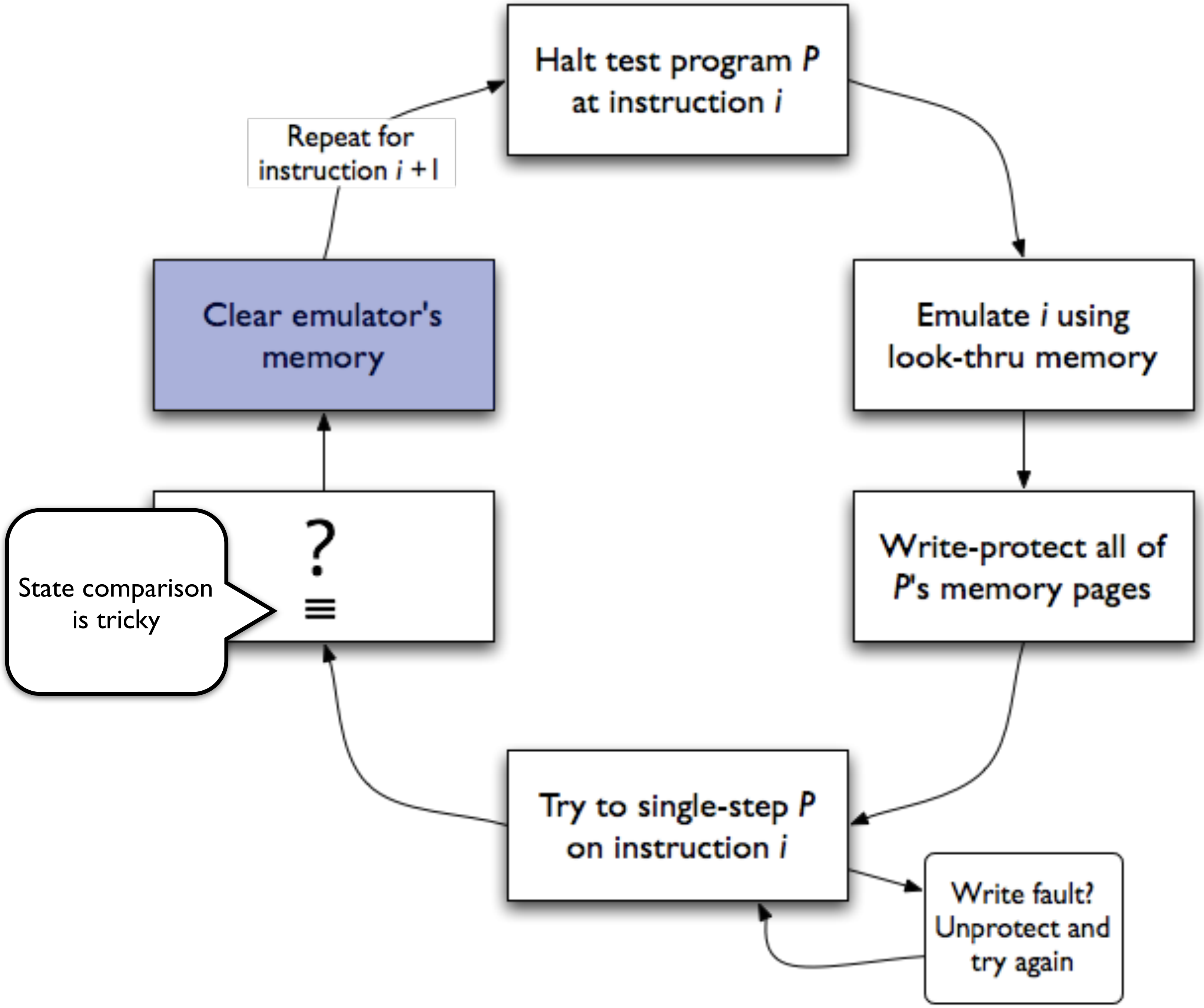
Execute instruction

E_1 $\overset{?}{\supseteq}$ E_1'

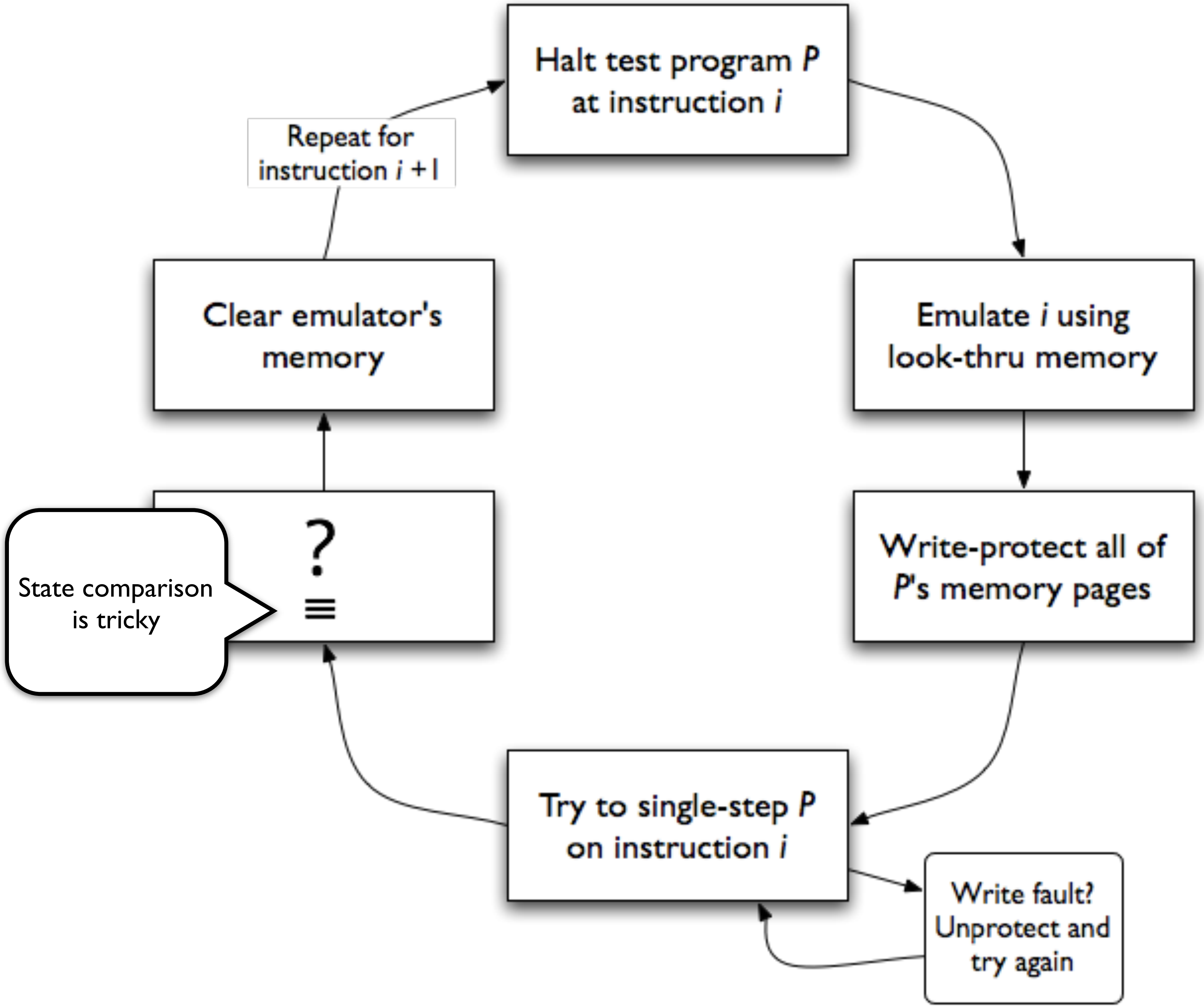
α "Abstract"

P_1

TSL validator main loop


Halt test program *P* at instruction *i*
Emulate *i* using look-thru memory
Write-protect all of *P*'s memory pages
Try to single-step *P* on instruction *i*
Write fault? Unprotect and try again
?
≡
State comparison is tricky
Clear emulator's memory
Repeat for instruction *i* +1

TSL validator main loop


Halt test program *P* at instruction *i*
Emulate *i* using look-thru memory
Write-protect all of *P*'s memory pages
Try to single-step *P* on instruction *i*
Write fault? Unprotect and try again
? ≡
State comparison is tricky
Clear emulator's memory
Repeat for instruction *i* +1

Future work:
short-term stuff

Future work: short-term stuff

- **The hard part of state comparison**: identify changed locations on the real process side, and compare them with corresponding locations on the emulator side.

Future work: short-term stuff

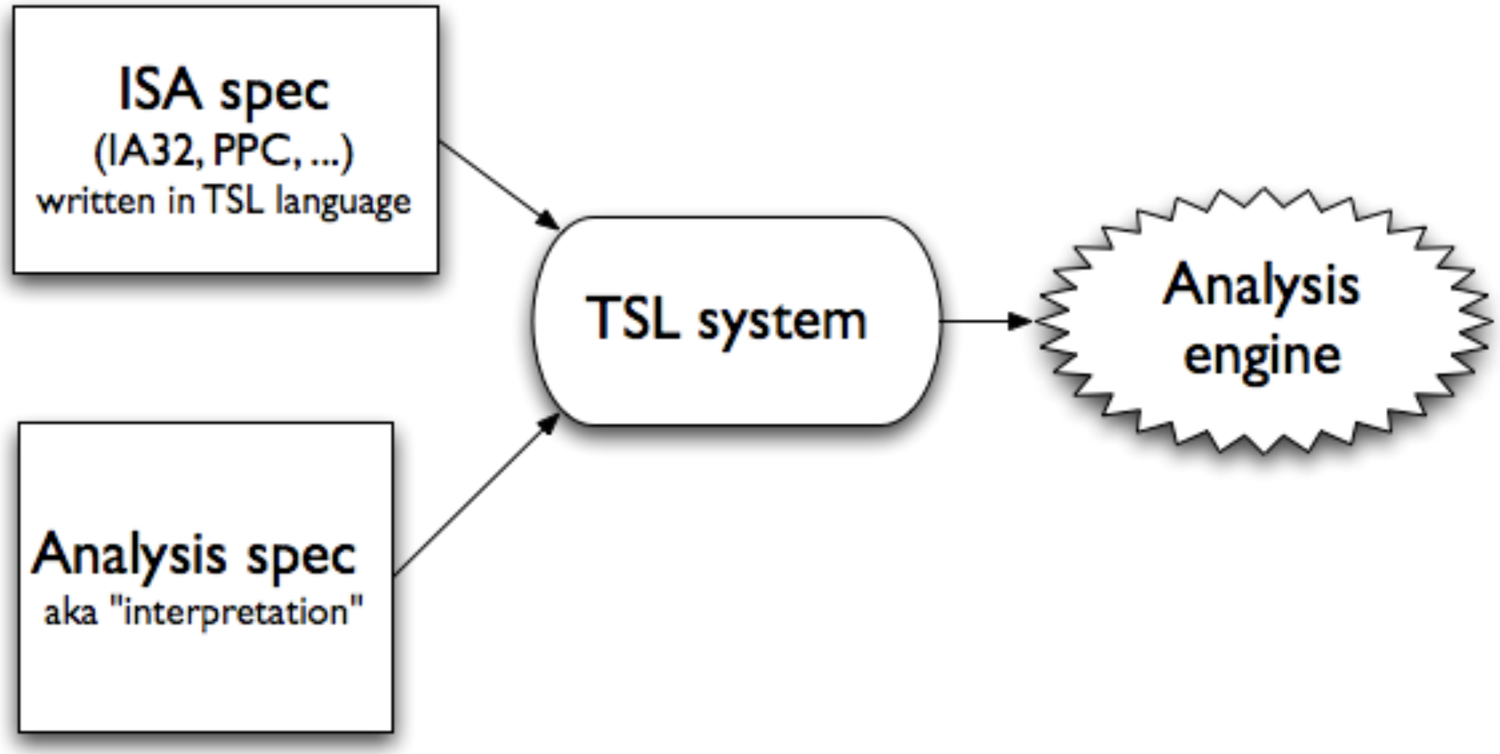
- **The hard part of state comparison**: identify changed locations on the real process side, and compare them with corresponding locations on the emulator side.
- Better logging and reporting: eventually, we'd like to have a "dashboard".

Future work: short-term stuff

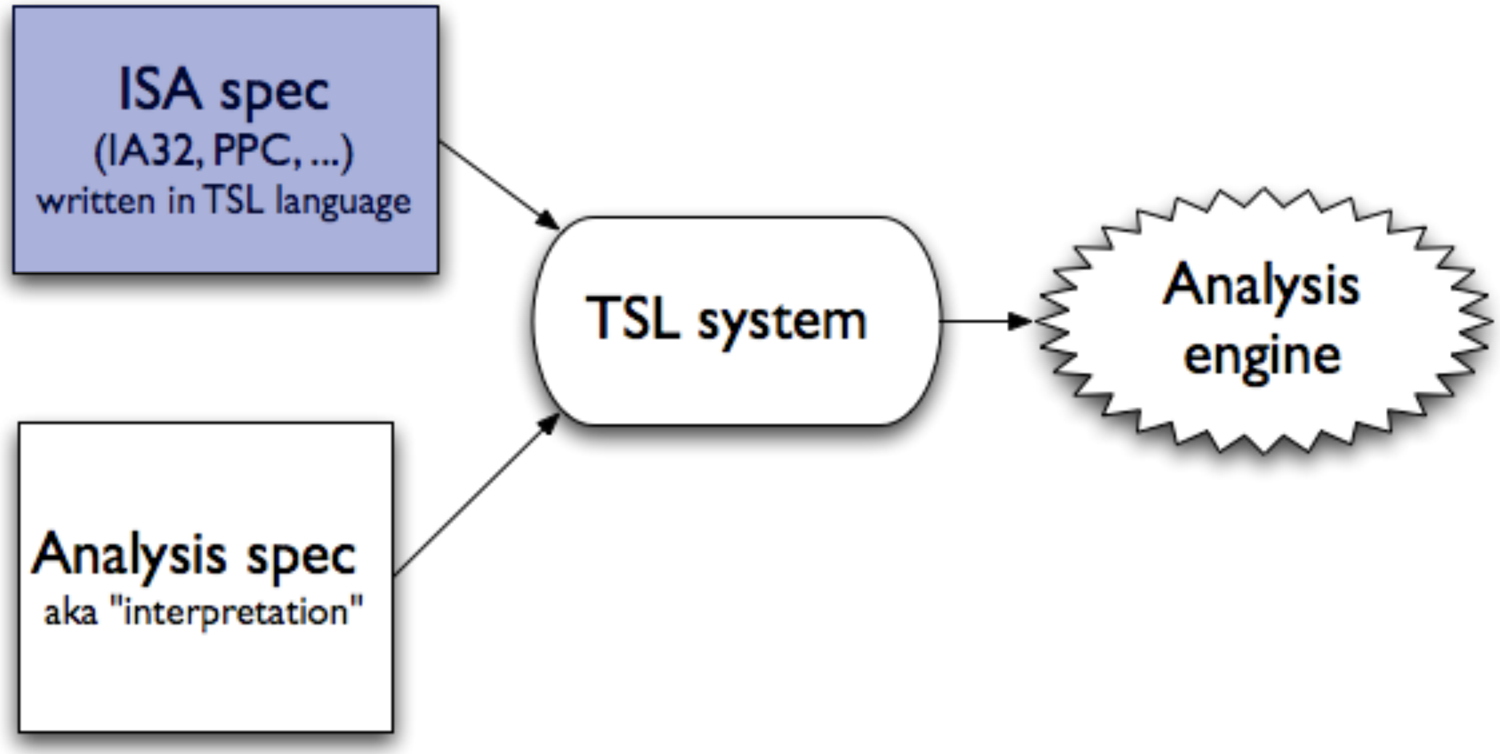
- **The hard part of state comparison**: identify changed locations on the real process side, and compare them with corresponding locations on the emulator side.
- Better logging and reporting: eventually, we'd like to have a "dashboard".
- How will we deal with test programs that "misbehave"?

Future work:
long-term stuff

Future work: long-term stuff

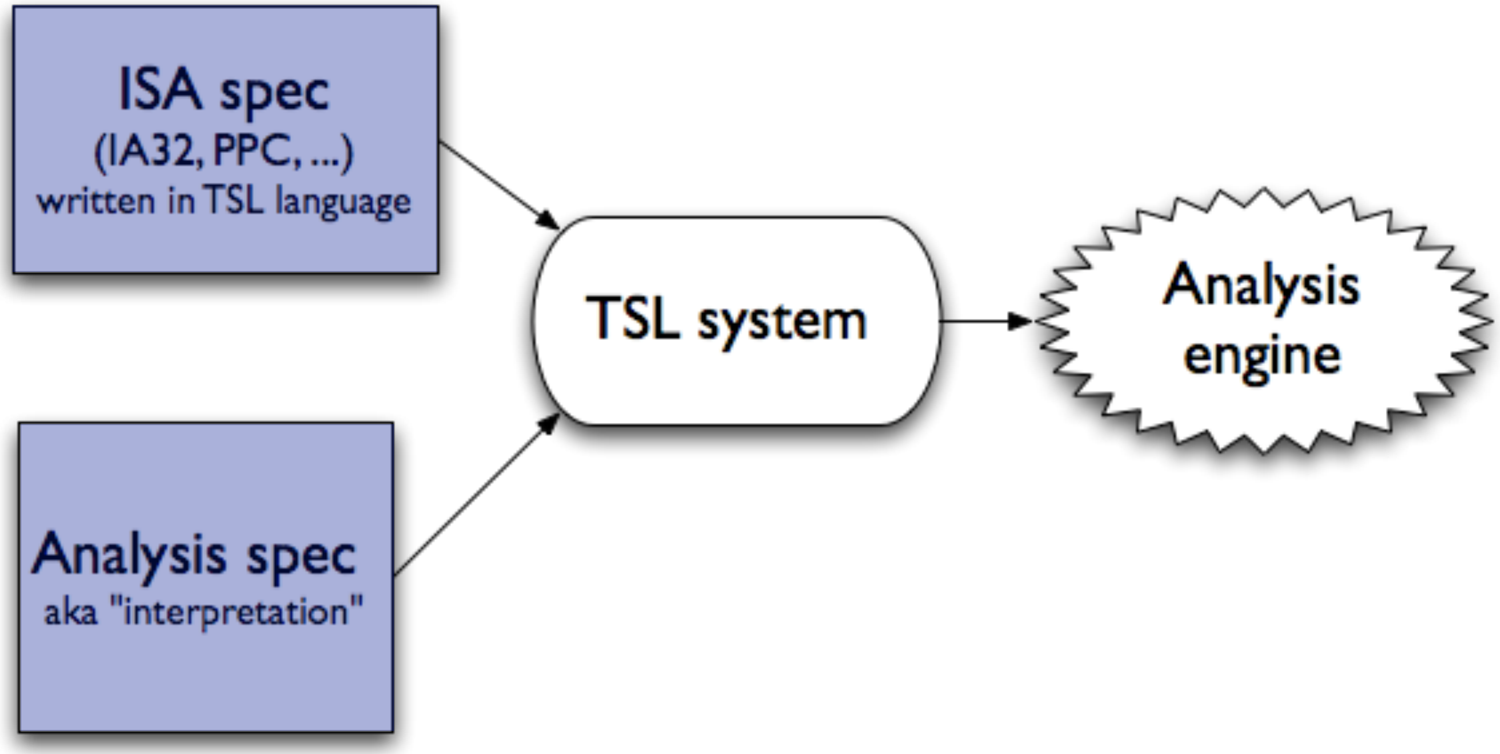


Future work: long-term stuff



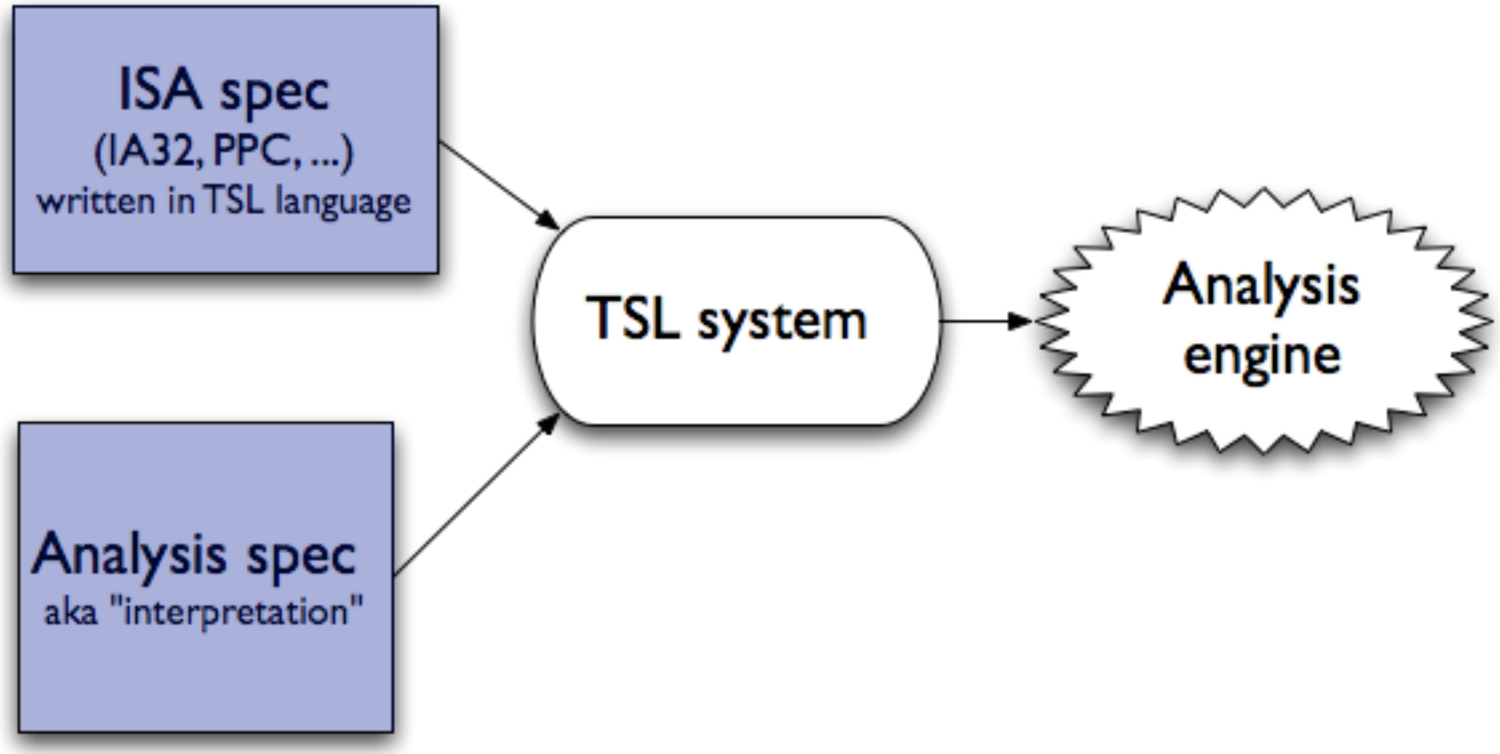
- Support for more ISAs. (x64, at least!)

Future work: long-term stuff



- Support for more ISAs. (x64, at least!)
- **Support for abstract interpretations**, not just EMUL.

Future work: long-term stuff



- Support for more ISAs. (x64, at least!)
- **Support for abstract interpretations**, not just EMUL.
- Find ways to choose which inputs to test that will be most likely to turn up bugs in a specification.

What I learned

What I learned

- Emulators, debuggers, and static analyzers are not made of magic

What I learned

- Emulators, debuggers, and static analyzers are not made of magic
- First real systems programming experience: didn’t quite cross the kernel space boundary, but came right up next to it

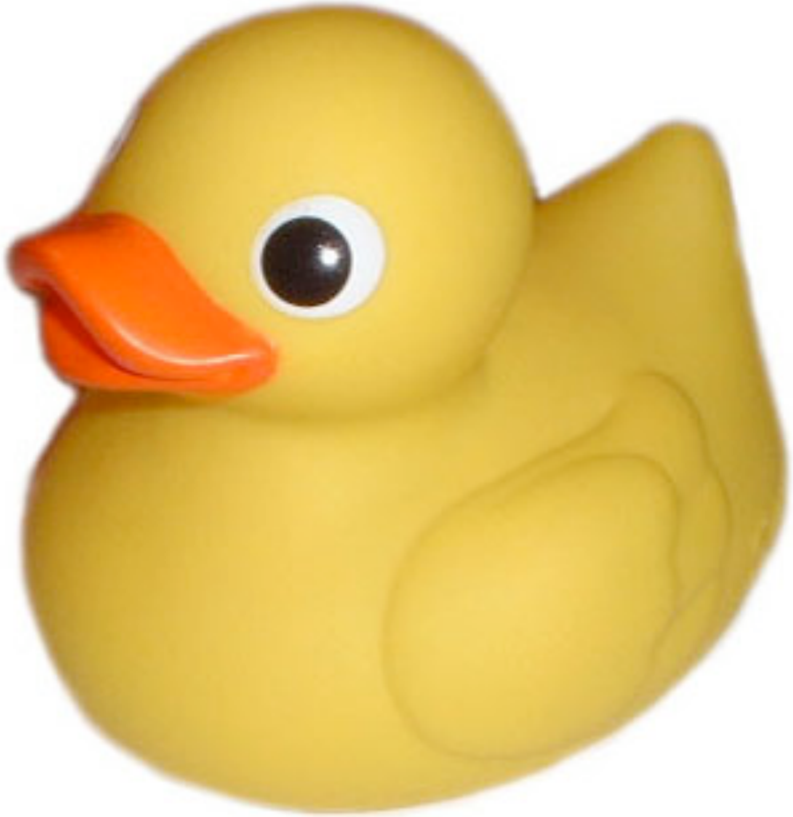
What I learned

- Emulators, debuggers, and static analyzers are not made of magic
- First real systems programming experience: didn't quite cross the kernel space boundary, but came right up next to it
- A metric for how much I can accomplish in 13 weeks

What I learned

- Emulators, debuggers, and static analyzers are not made of magic
- First real systems programming experience: didn’t quite cross the kernel space boundary, but came right up next to it
- A metric for how much I can accomplish in 13 weeks
- Finally convinced that OOP is good for something

Thank you!



Questions?

```
(exit)
```