The Behavior of Gradual Types: A User Study

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Intuition: Gradual Typing

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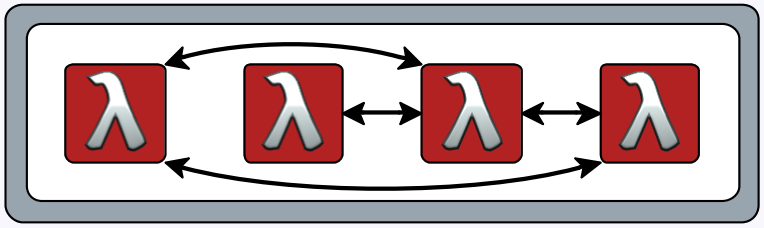
Dynamic Typing



un(i)typed components
value safe

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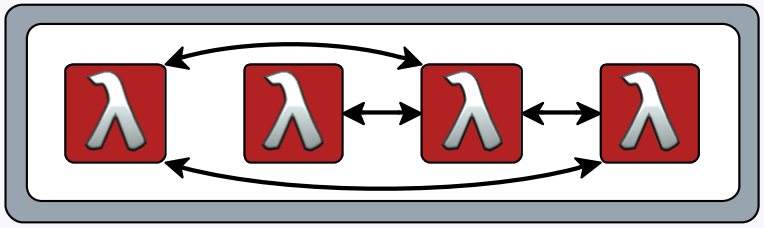

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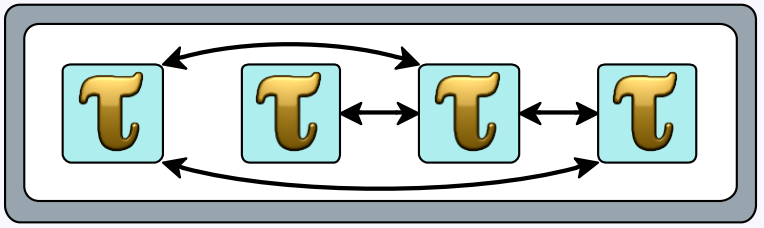

typed components
type safe

Intuition: Gradual Typing

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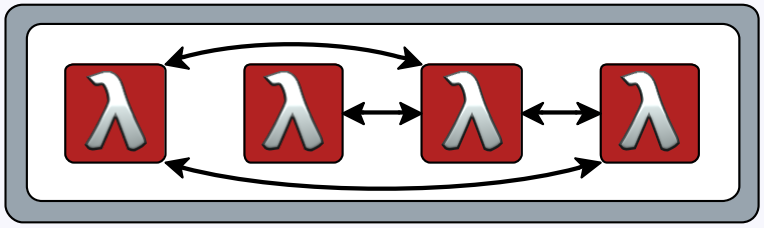

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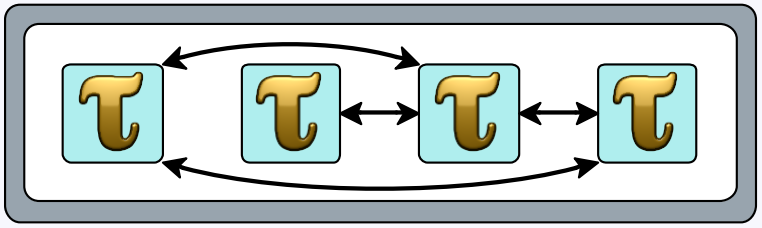
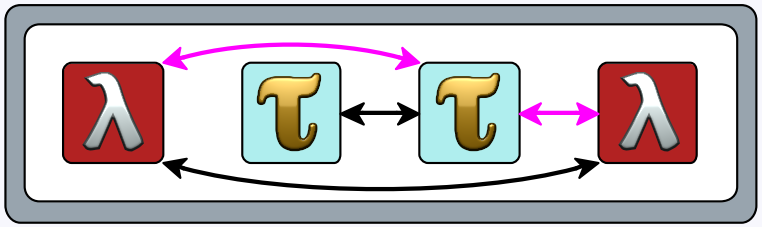


typed components
type safe

Gradual Typing



typed + untyped components
.... safe?

Gradual Typing Helps Programmers?

DLS'14

Combining static and dynamic typing within the same language **offers clear benefits** to programmers

Gradual Typing Helps Programmers?

ESOP'12

We conjecture that a **programmer would like** the guarantee that the values produced by their components are never used in violation to the interface specifications ...

Gradual Typing Helps Programmers?

POPL'17

... [run-time checks] inspect the top-level type (or type-tag) of each value, ensuring safe interaction and providing **the expected type safety** to programmers

Gradual Typing Helps Programmers?

A programmer **may favour** unsound monitoring over wrappers that change the semantics of their program.

ECOOP'17

Gradual Typing Helps Programmers?

Being sound, Safe TypeScript endows types with many of the properties that Java or C# programmers **might expect** but not find in TypeScript

The system **lives up to all expectations** that developers have of sound language implementations.

... programmers should be able to add or remove type annotations without any **unexpected** impacts on their program

POPL'15

SNAPL'17

SNAPL'15

POPL'08

OOPSLA'17

ECOOP'14

Data to Support Claims?

`DLS'14`

`ESOP'12`

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Data to Support Claims?

DLS'14	✗
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SNAPL'15	✗
POPL'08	✗
OOPSLA'17	✗
ECOOP'14	✗

Three Different Approaches!

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Deep

types are sound/enforced

Shallow

Erasure

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types are sound/enforced

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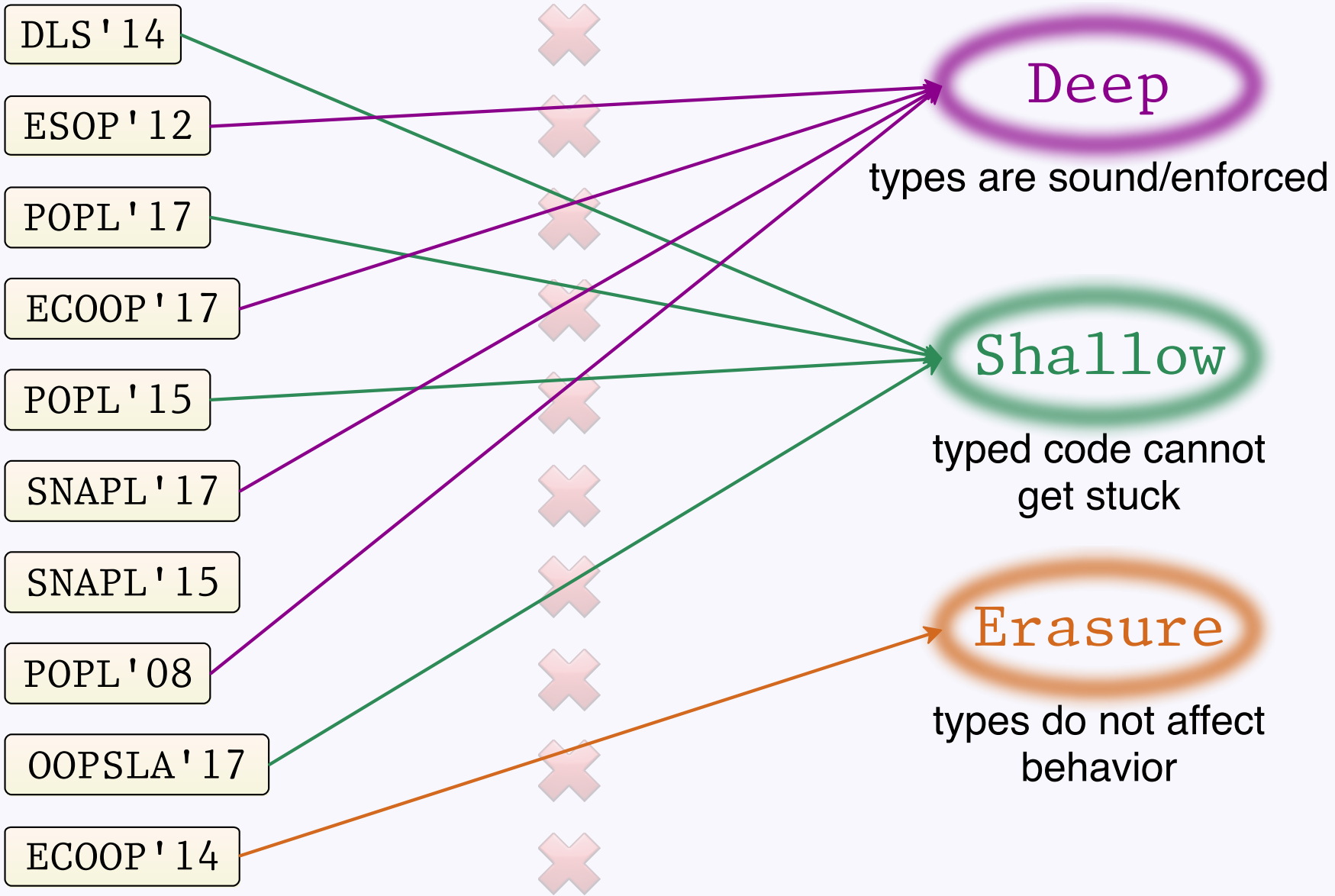
Erasure

types do not affect behavior

Three Different Approaches!



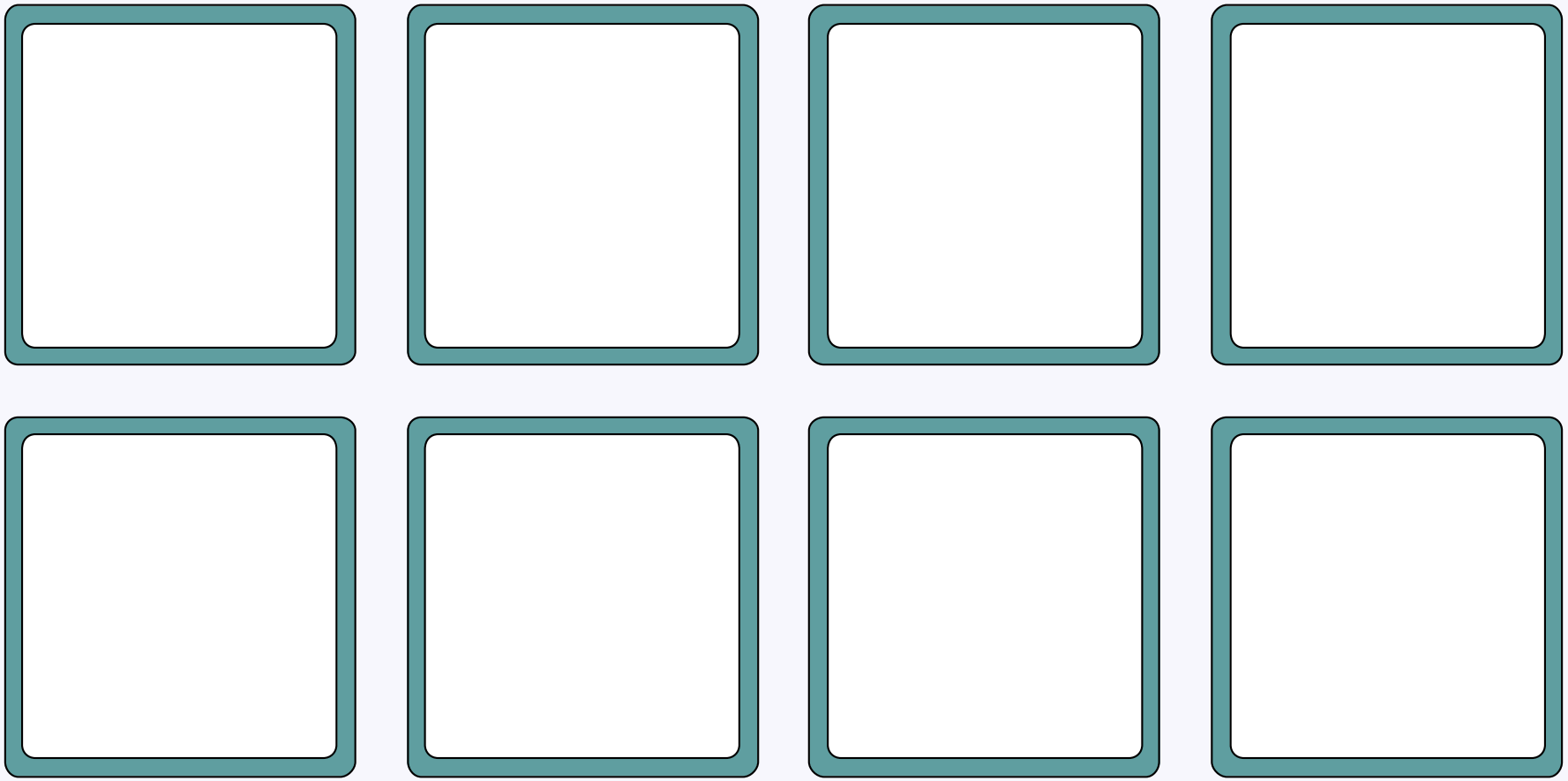
In this paper:

We begin to **address the lack of data** with a **developer survey** contrasting the different approaches to gradual typing

Deep vs. Shallow

Erasure

Survey based on 8 example programs



Survey Prompt

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Question 7

```
1 var x : Array(String) = ["hi" "bye"];
2 var y = x;
3 var z : Array(Number) = y;
4 z[0] = 42;
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```

Question 7

Type annotations

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Array operations

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Multiple behaviors (unlabeled)

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`"bye"`

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Error: line 4 expected `String` got 42

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"bye"

(Deep)
(Shallow)
(Erasure)

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	Like	Dislike
Expected		
Unexpected		

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LE	LU	DE	DU
○	○	○	○
○	○	○	○
○	○	○	○

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Question 5

Two distinct behaviors

```
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"hello"
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(Deep,Shallow)
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	LE	LU	DE	DU
Error: line 1 expected Number got "hello"	○	○	○	○
"hello"	○	○	○	○

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Objects instead of closures, to avoid confusion

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Error: line 1 expected Number got "hello"	○	○	○	○
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Followup Question

Agree/Disagree: Type annotations should not change the behavior of a program.

Summary: Survey Design

Solicit opinions on the semantics of a "new" language

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We are designing a language that mixes typed and untyped code.
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Gather `Like` × `Expect` preference on eight small programs designed to classify approaches

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Explicit followup about optional typing

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Why 8?

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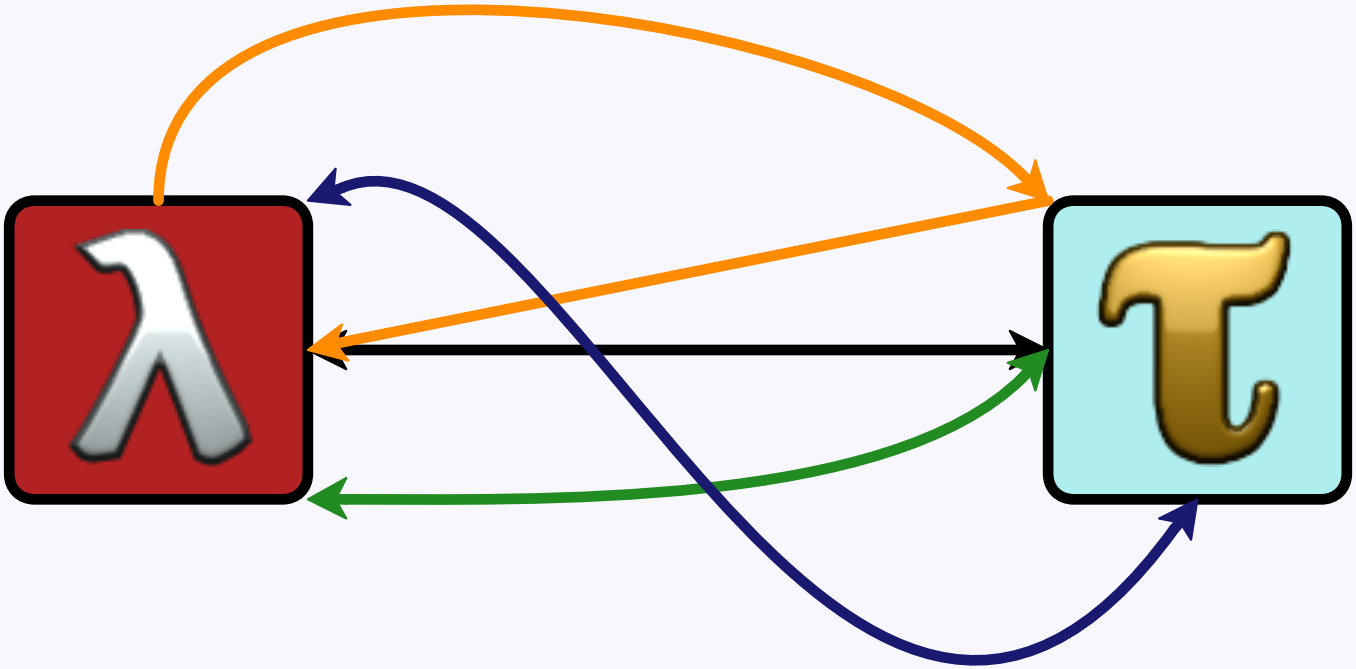
Followup Question

> *Agree/Disagree*: Type annotations should not change the behavior of a program.

Goal: cover all interactions



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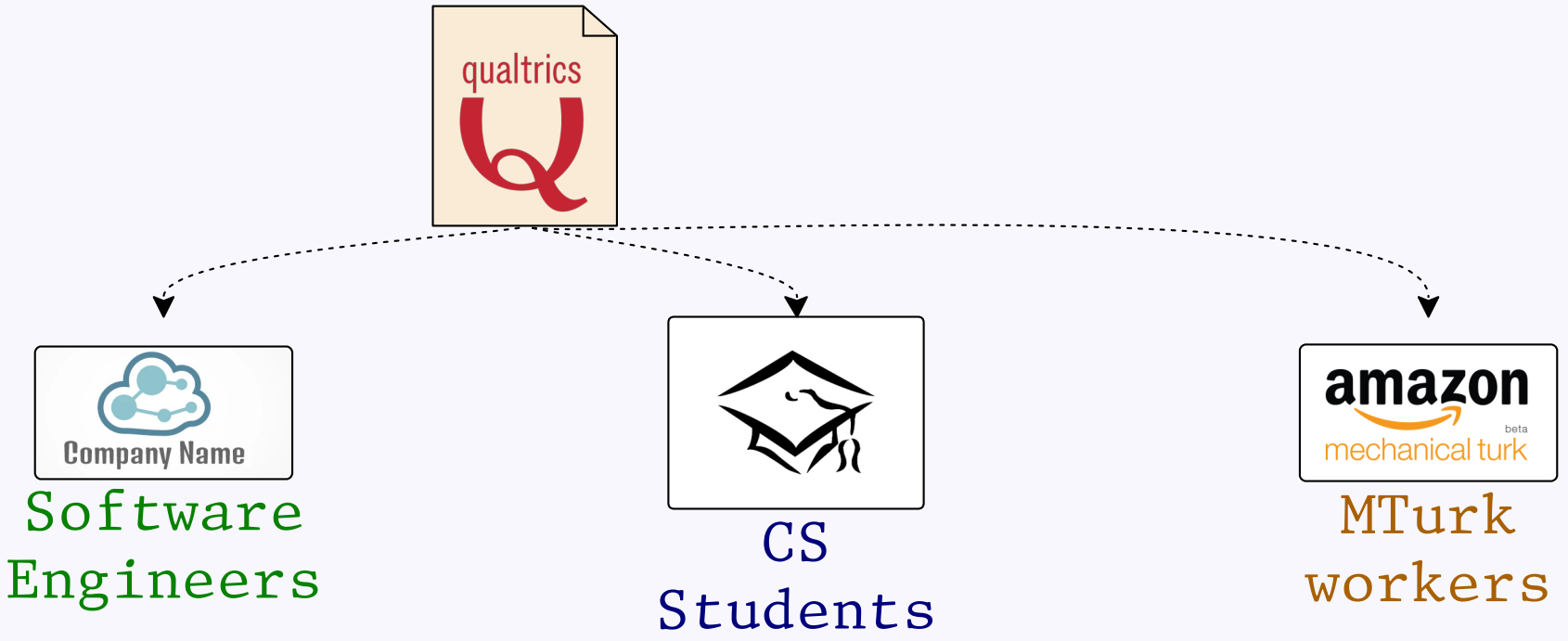

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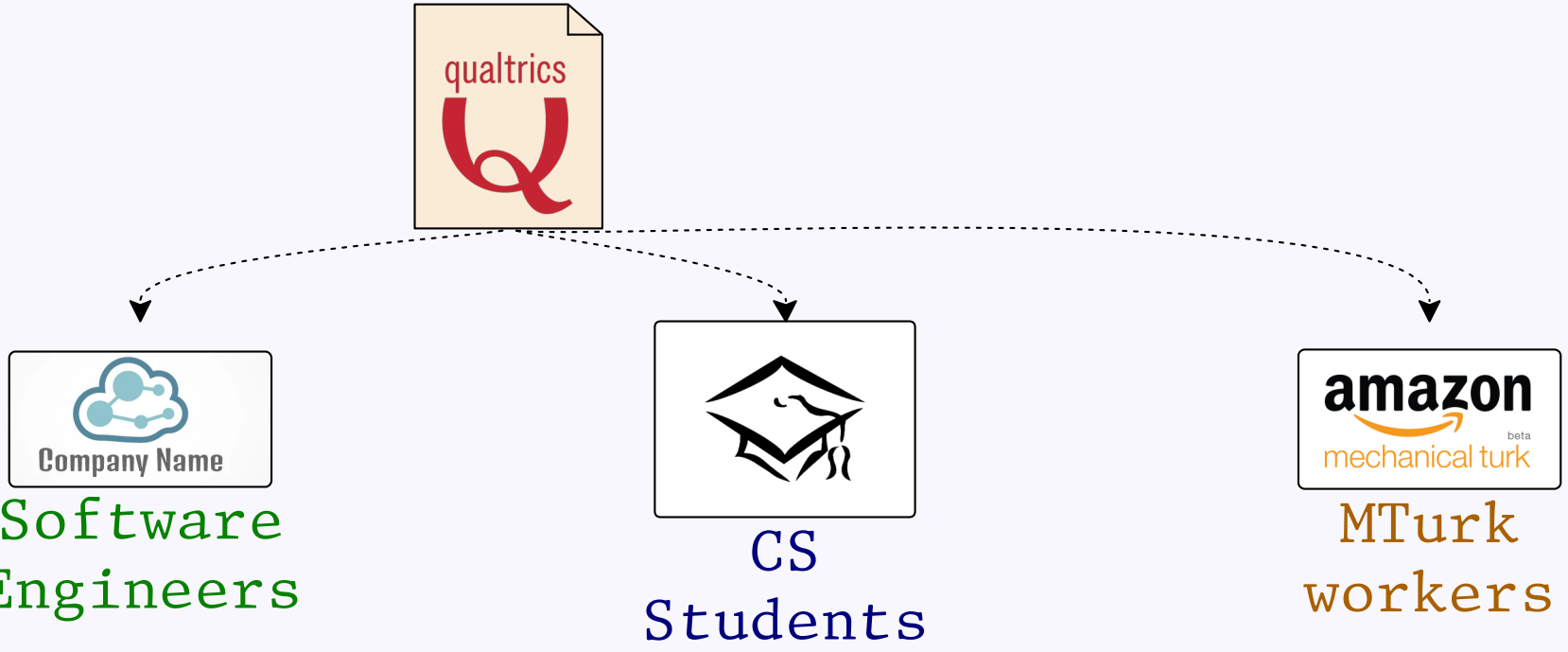

Software Engineers

CS Students

MTurk workers

34 participants

17 participants

90 participants
(96 filtered)

Results

Question 1

```
1 | var t = [4, 4];
2 | var x : Number = t;
3 | x
```

	LE	LU	DE	DU
Error: line 2 expected `Number` got `[4, 4]`	○	○	○	○
`[4, 4]`	○	○	○	○

Question 1

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1 | var t = [4, 4];
2 | var x : Number = t;
3 | x
```
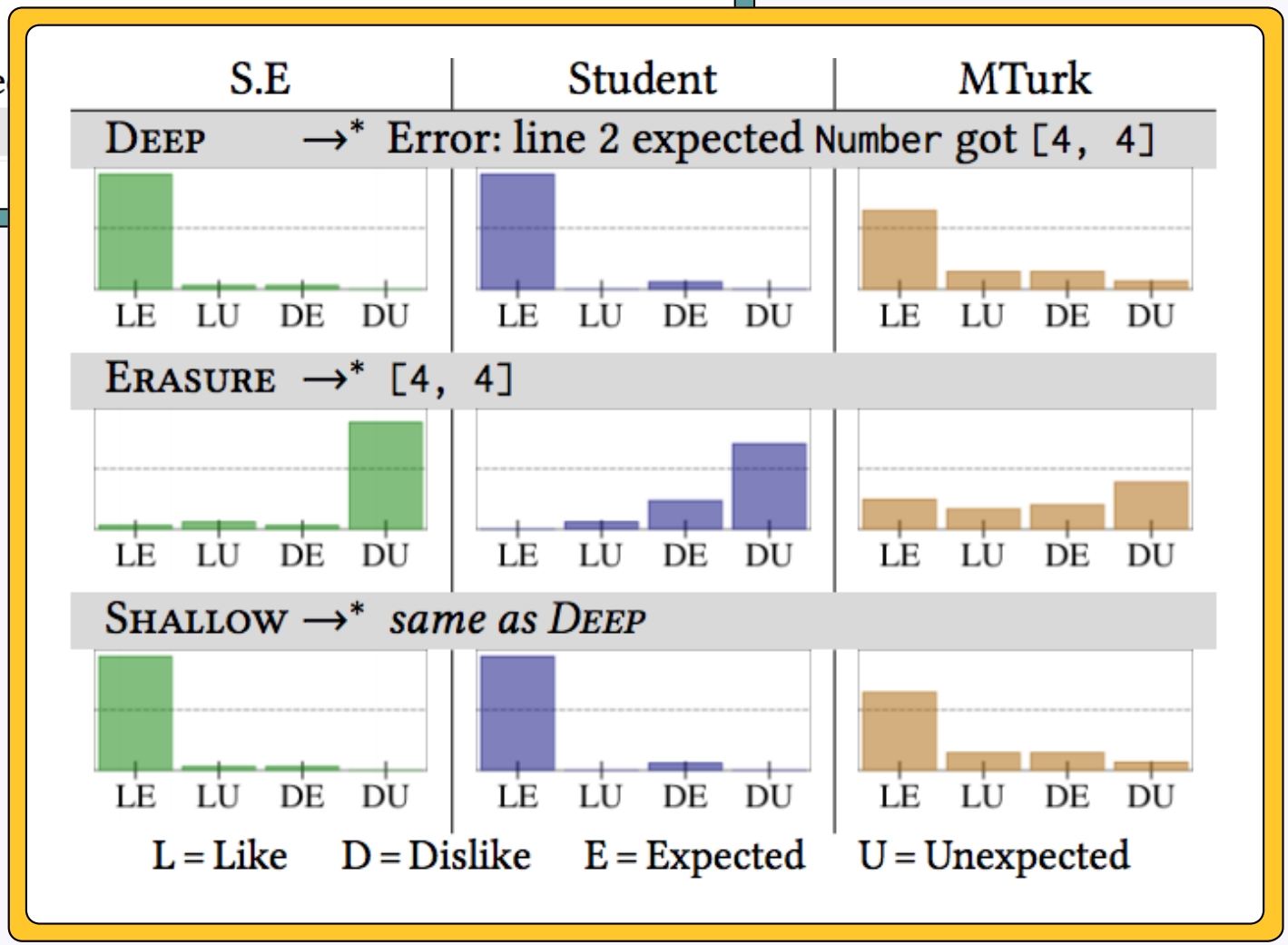

Error: line 2 expecte

```
[4, 4]
```



Followup Question

Agree/Disagree: Type annotations should not change the behavior of a program.

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Agree/Disagree: Type annotations should not change the behavior of a program.

Software Engineers

44% agree

CS Students

12% agree

MTurk workers

51% agree

Conclusions

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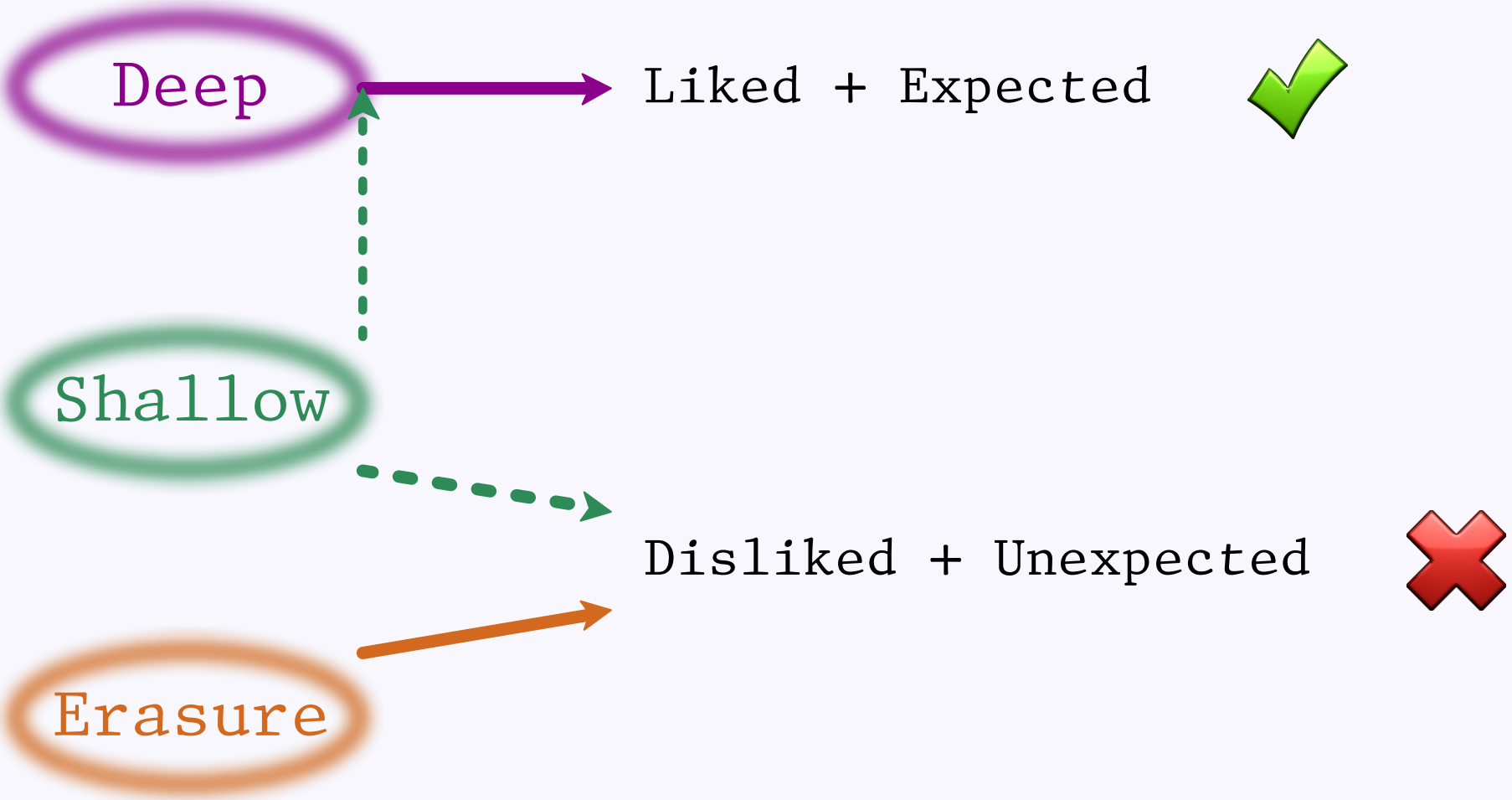

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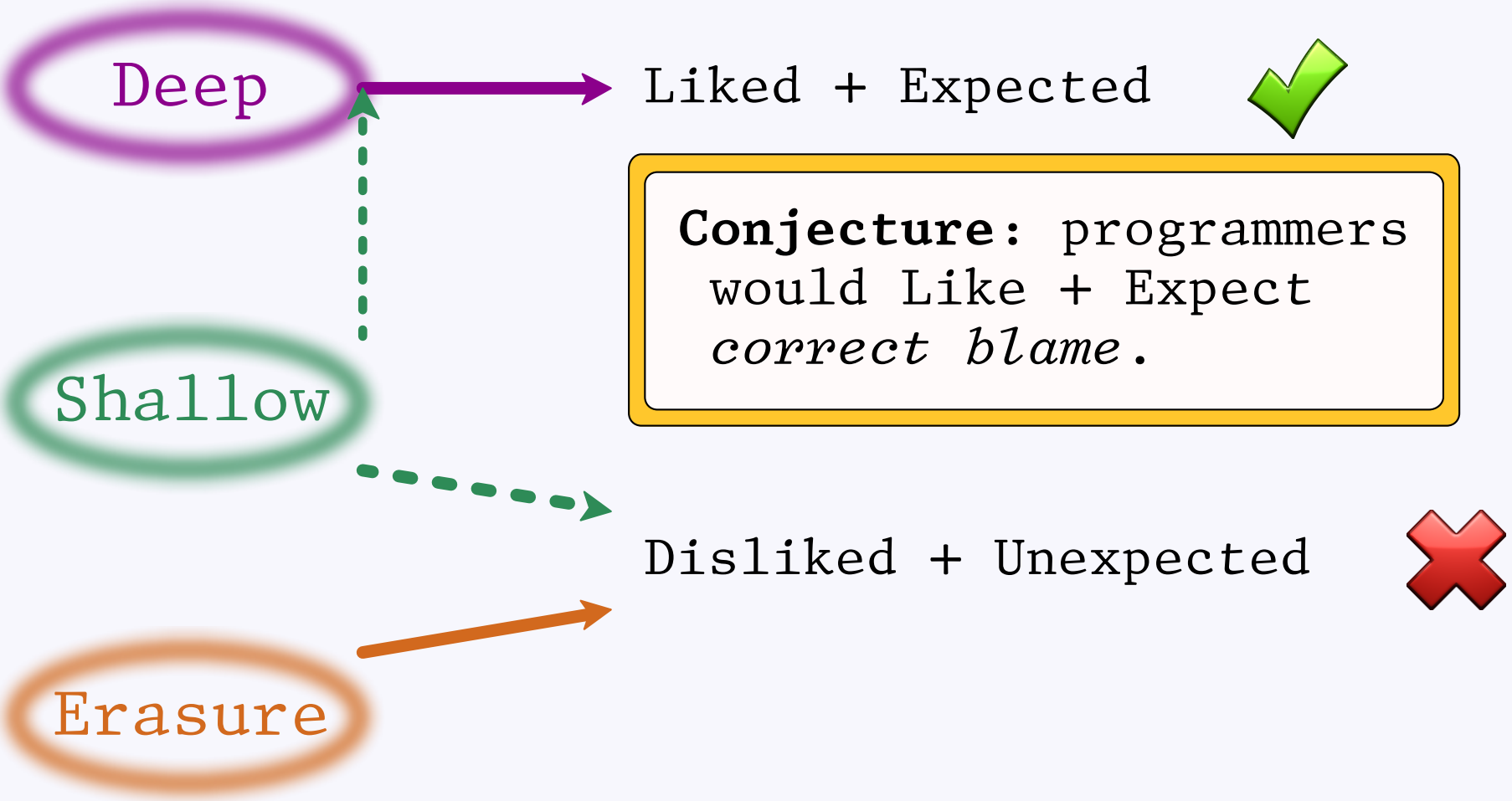

Takeaways

Unless there's a strong reason, choose Deep

Programmers seem to expect it!

Non-Deep languages must **document** their design and rationale

Start with the survey examples

cs.brown.edu/research/plt/dl/dls2018

Threats to Validity

Indirect questions ("new" language)

Possible ambiguity:

- lack of type inference
- interpretation of code / error outputs
- runtime vs. static errors

Threats to Generalizability

Selective engineer + student populations

Very diverse MTurk population

Other implications:

- runtime performance
- quality of error messages

Concrete Types

concrete = every value carries a runtime type

Limits expressiveness of "untyped" code

Preferred by Dart users?

Another point to explore!

Followup Question

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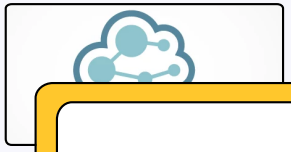

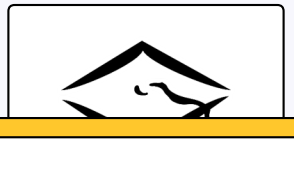

amazon

Pop.	Erasure Opinion	Agree	Disagree
S.E.	Like	1	0
	Dislike	14	19
Student	Like	0	0
	Dislike	2	14
MTurk	Like	19	11
	Dislike	18	25

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	LE	LU	DE	DU
Error: line 1 expected Number got "hello"	○	○	○	○
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```

Error: line 1 expected

```
"hello"
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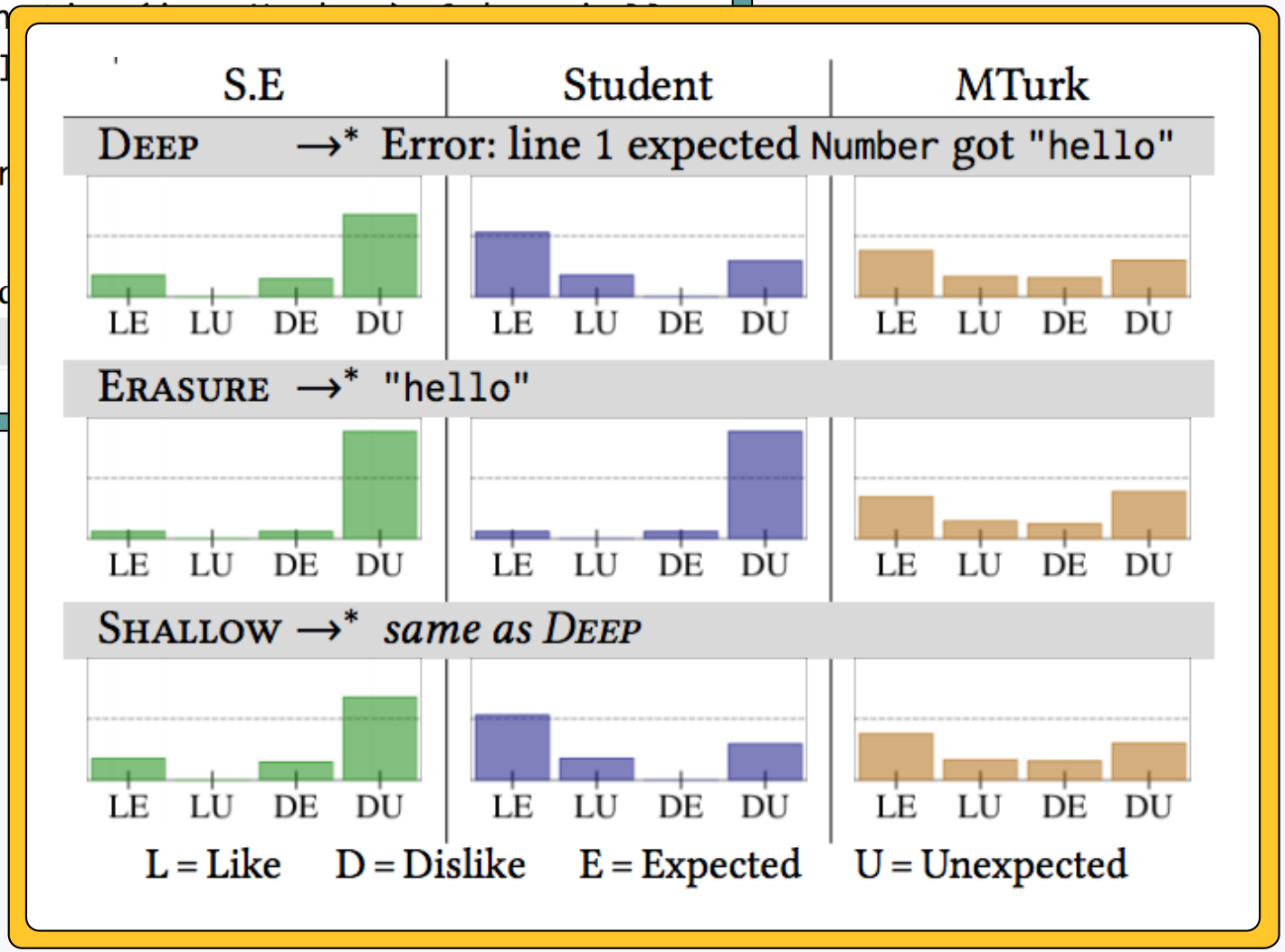

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	LE	LU	DE	DU
Error: line 1 expected Number got "hello"	○	○	○	○
"hello"	○	○	○	○

Why is the compiler complaining about line 1? The error message should be attached to **line 3**, that's the source of the problem!

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```

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Error: line 3 expected Number got "hello"	○	○	○	○
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```

Error: line 3 expected

"hello"

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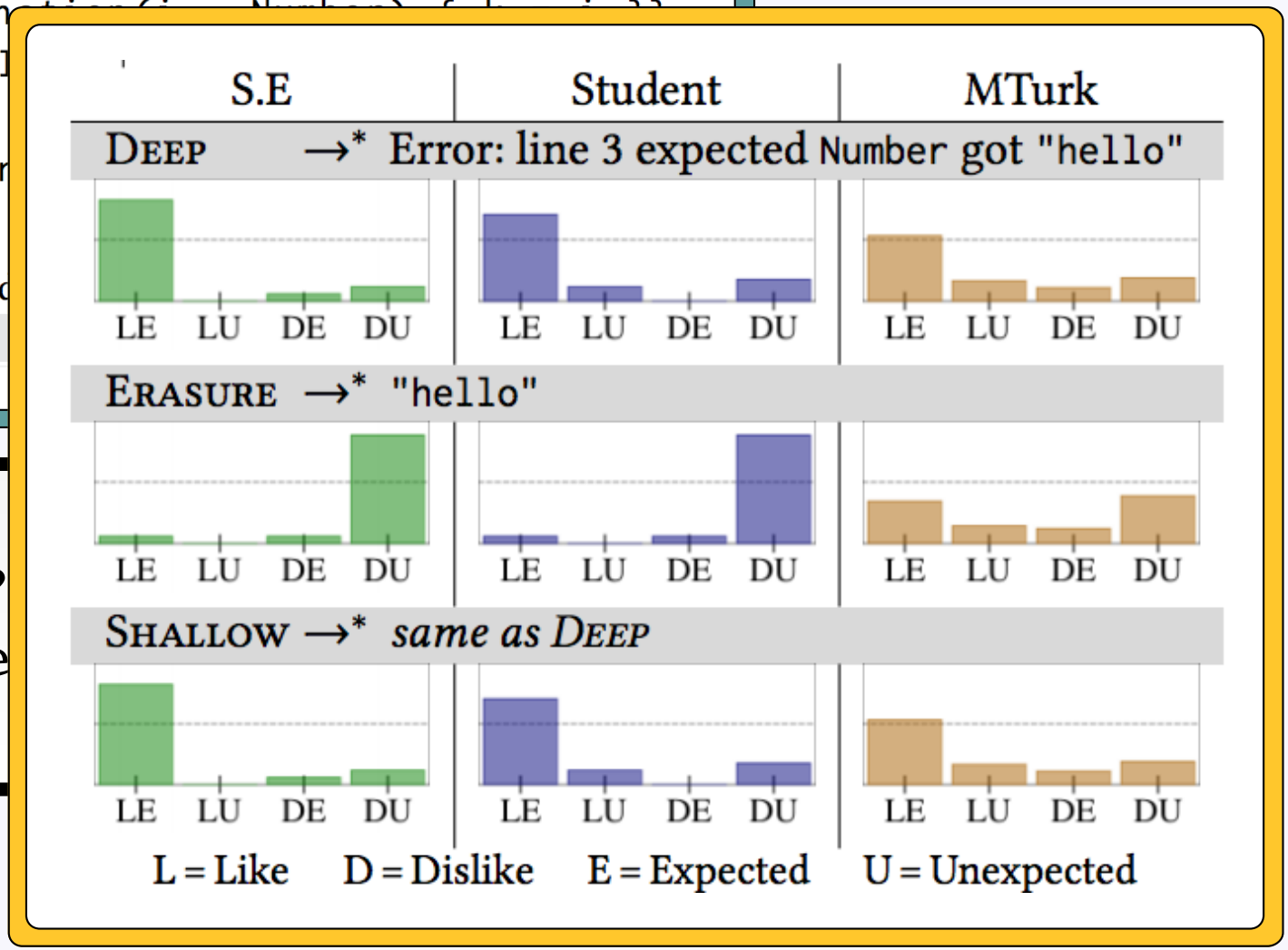
line 1?
attache
of the



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Error: line 4 expected String got 42	○	○	○	○
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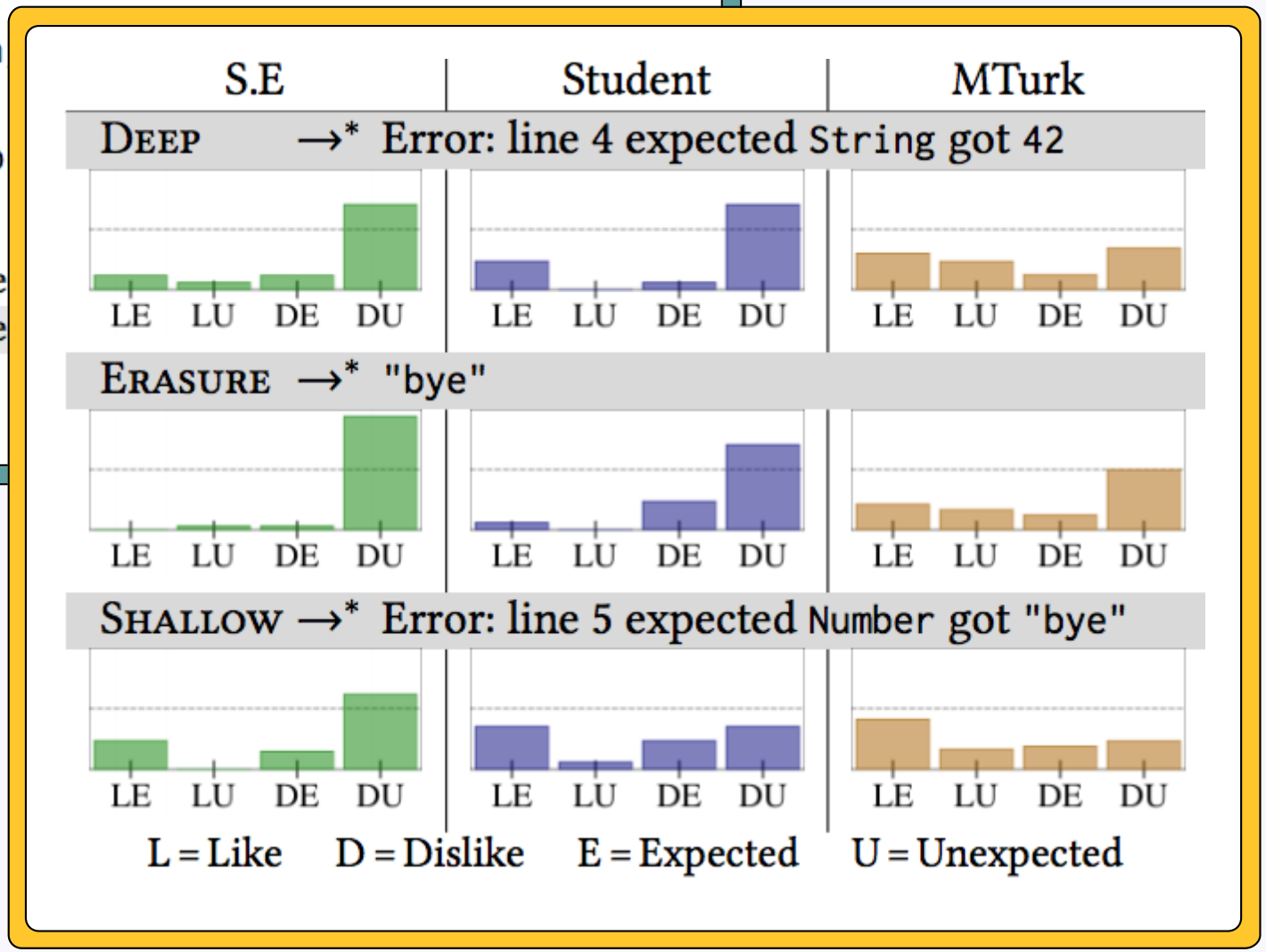


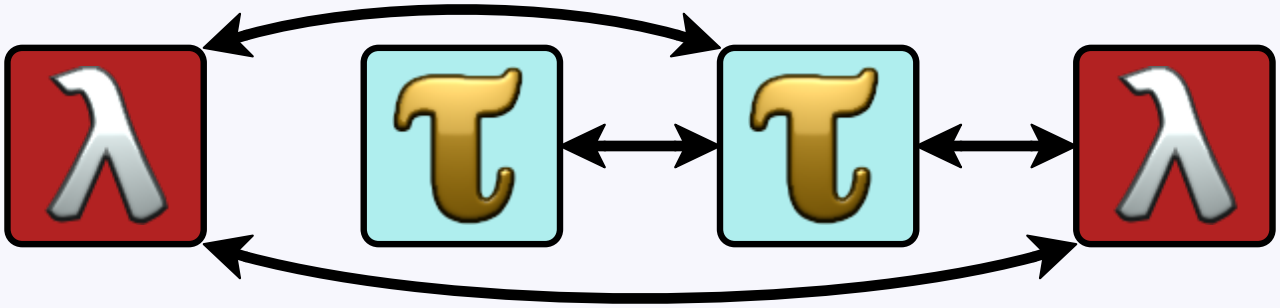
`Shallow` cannot get 'stuck' if:

1. Total reduction relation for dynamic code

2. Partial reduction relation for static code (possible to get stuck)

3. Shallow checks can distinguish stuck vs. non-stuck states

Three Approaches to G.T.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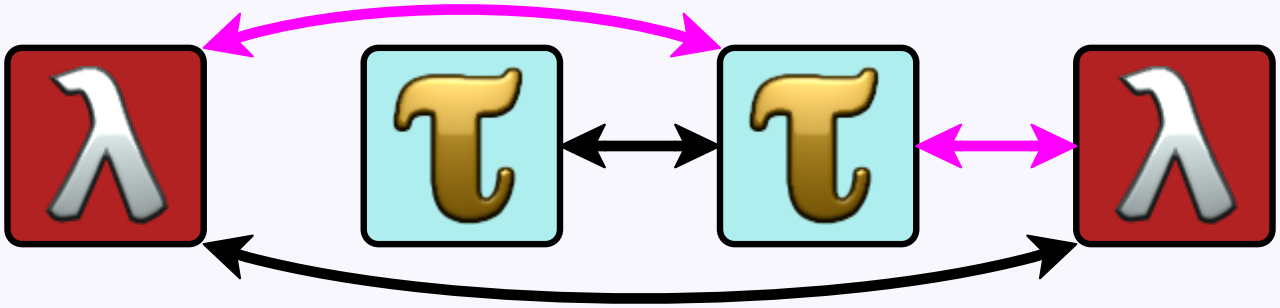
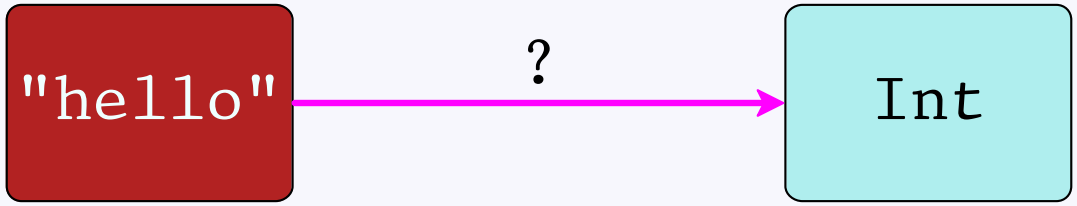
How to enforce the type boundaries?



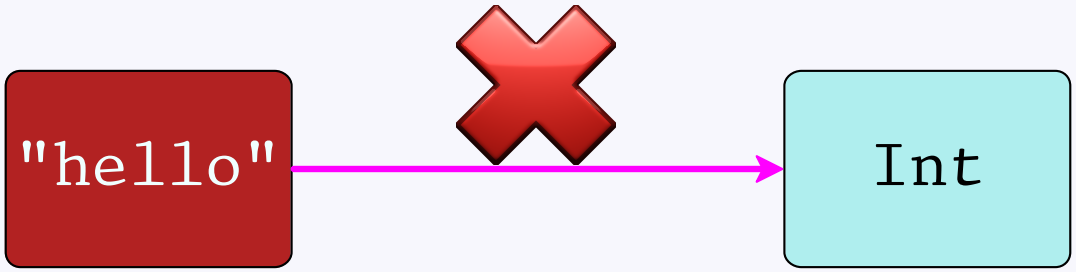
Example: Base Type

Deep Shallow Erasure

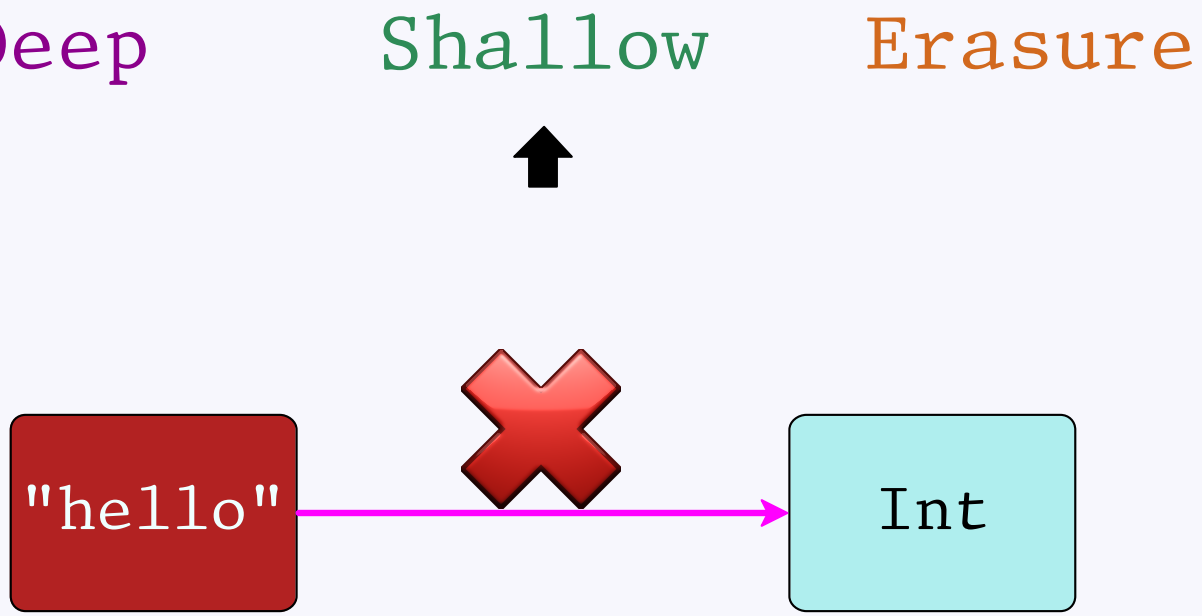


Example: Base Type

Deep Shallow Erasure

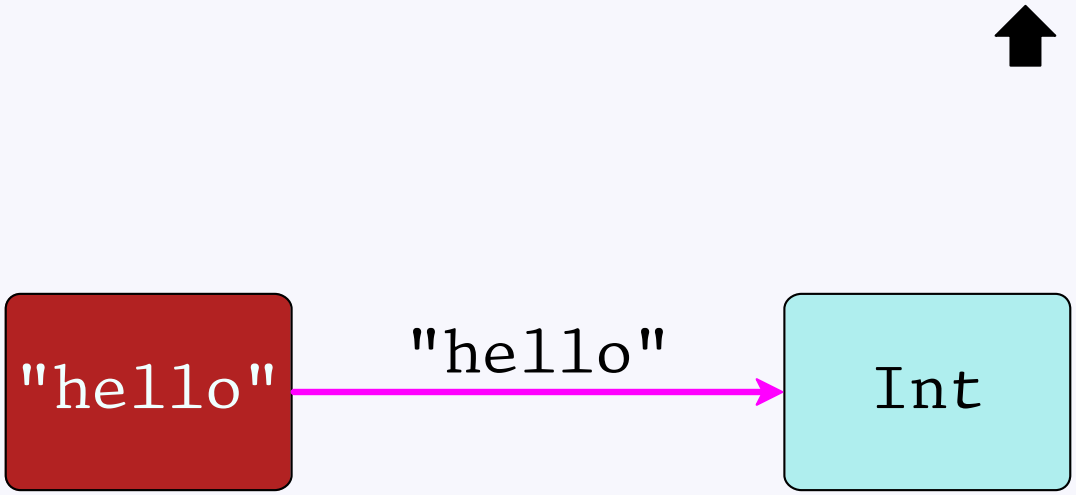


Example: Base Type



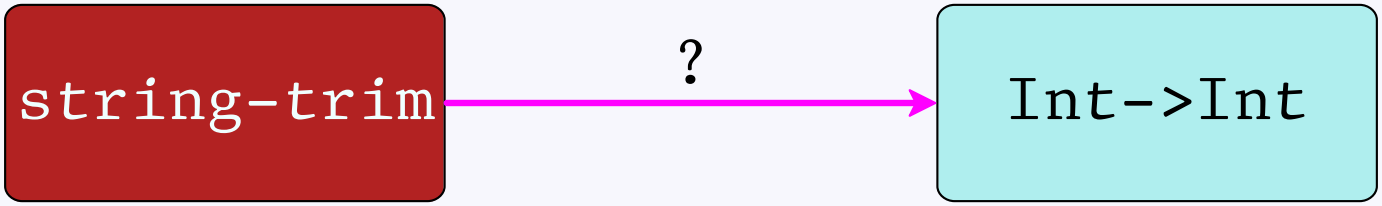
Example: Base Type

Deep Shallow Erasure



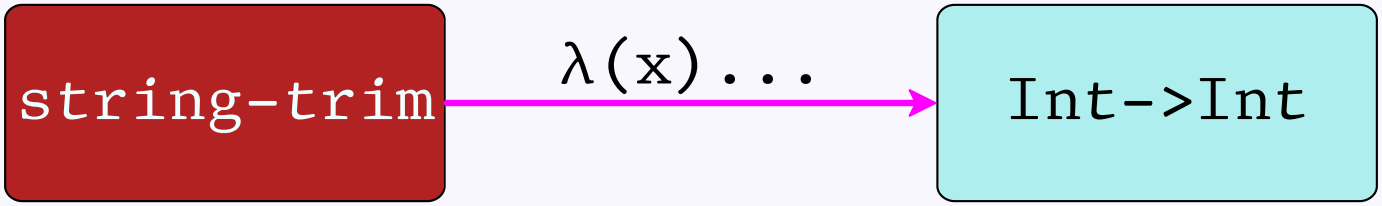
Example: Higher-Order Type

Deep Shallow Erasure



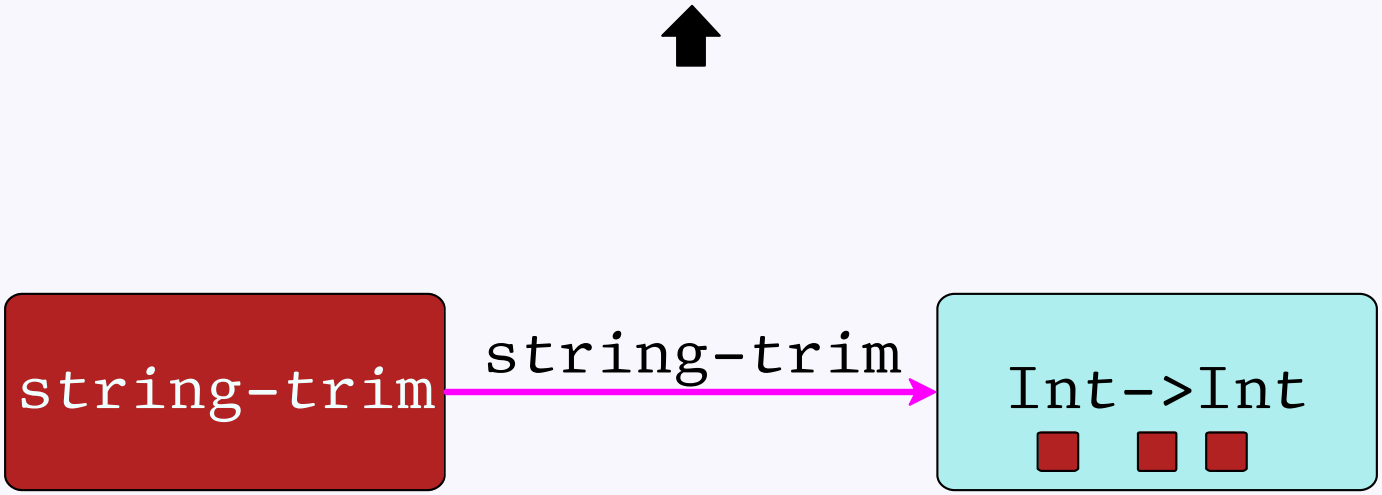
Example: Higher-Order Type

Deep Shallow Erasure



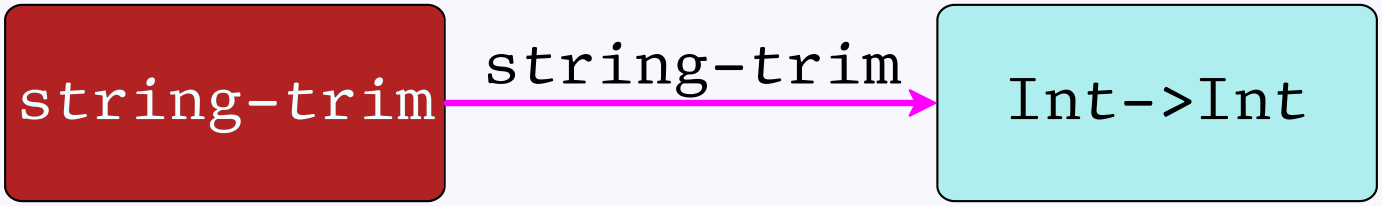
Example: Higher-Order Type

Deep Shallow Erasure



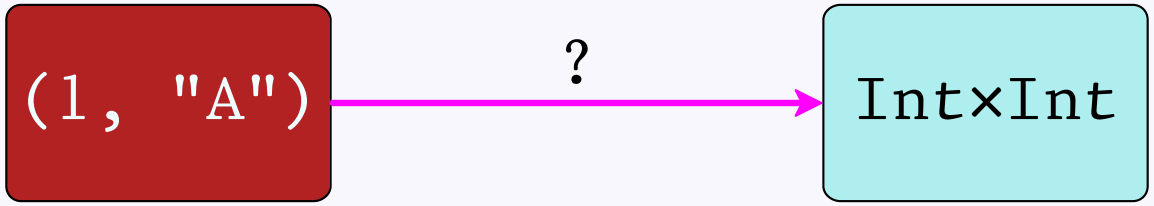
Example: Higher-Order Type

Deep Shallow Erasure



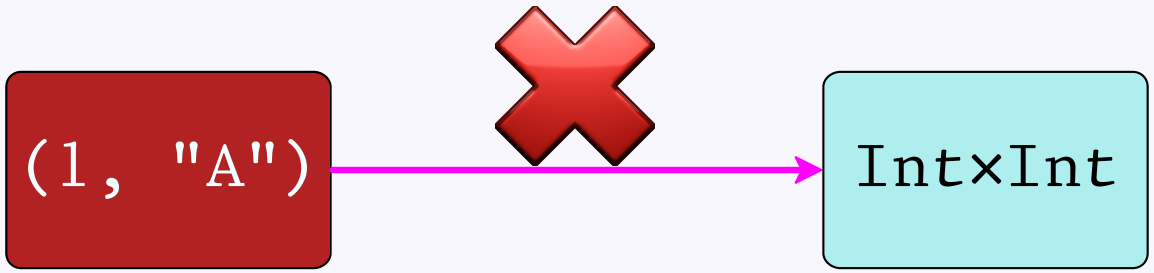
Example: Inductive Type

Deep Shallow Erasure



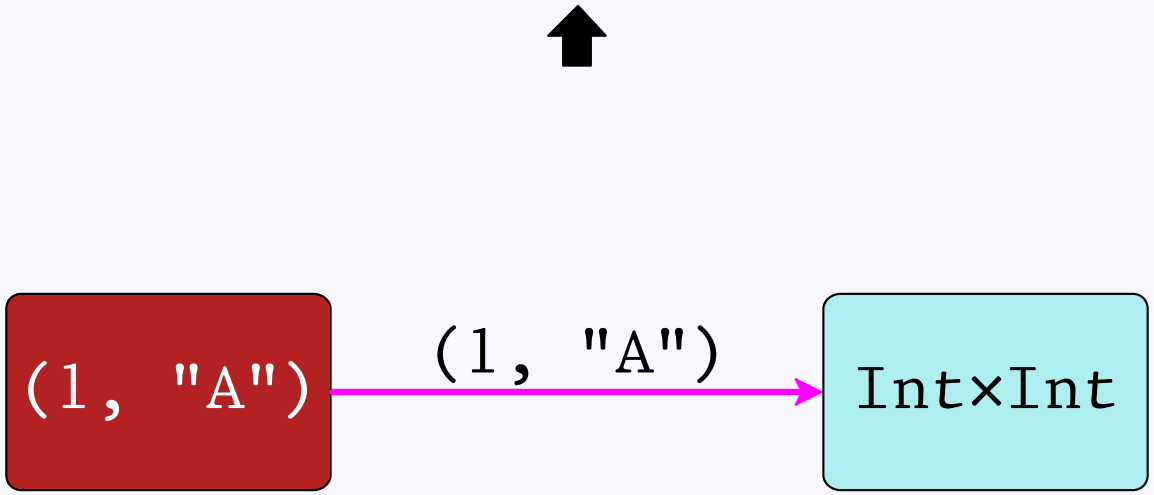
Example: Inductive Type

Deep Shallow Erasure



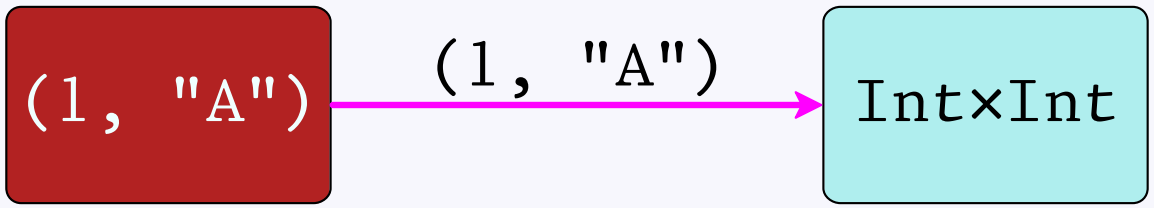
Example: Inductive Type

Deep Shallow Erasure



Example: Inductive Type

Deep Shallow Erasure



Three Approaches, Summary

	Deep	Shallow	Erasure
invariant	t	C(t)	v
base types	check	check	-
coinductive types	wrap	check	-
inductive types	traverse	check	-
boundaries	static, higher-order	static, selectors	-