


CZ: Multiple Inheritance Without Diamonds



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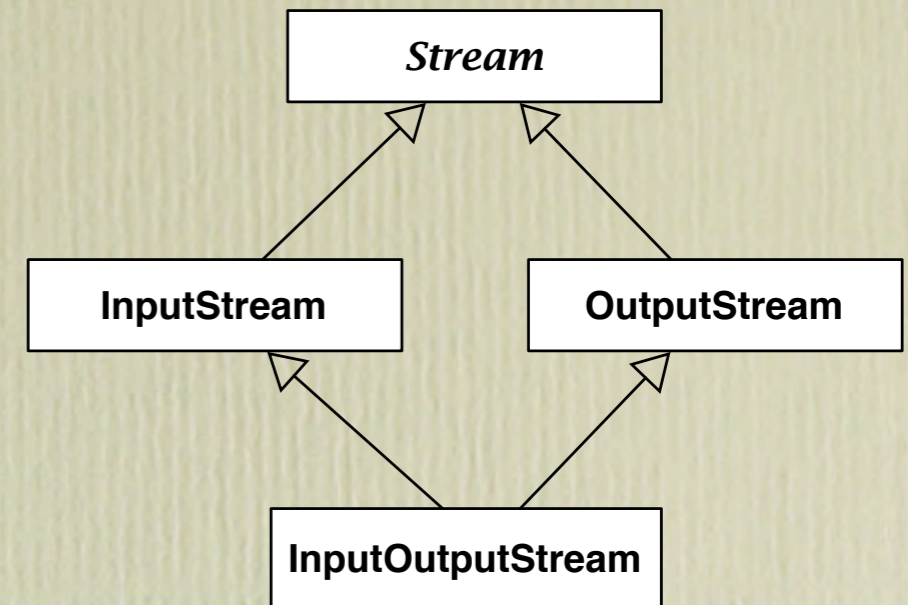
Multiple inheritance can be useful

- More flexible than single inheritance
- More opportunities for code reuse
- Can express multiple “dimensions” of behavior implemented by a class

Multiple inheritance can be problematic

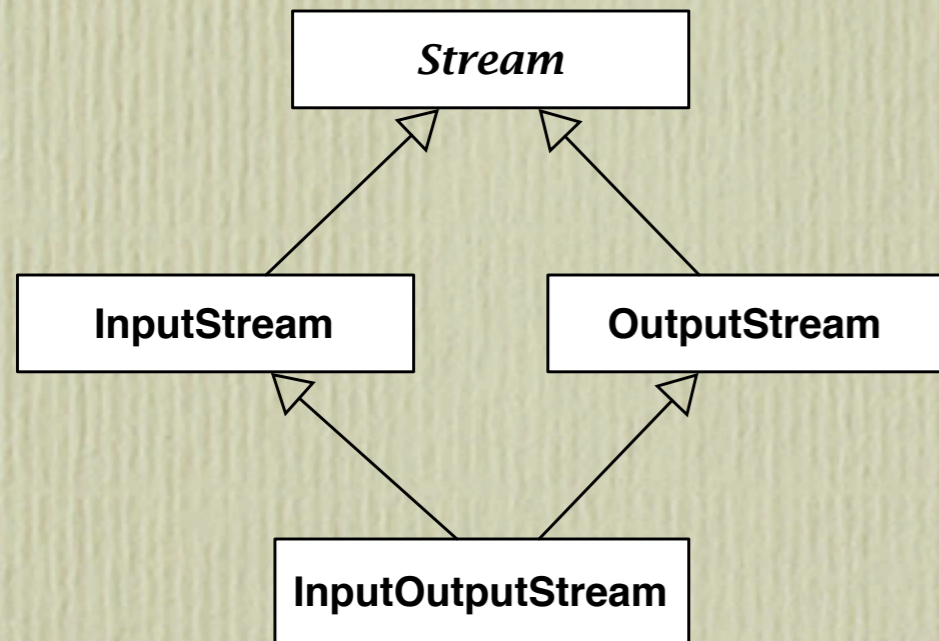
- Name clashes
 - Possible solution: allow renaming (e.g. Eiffel)
- Inheritance diamonds
 - Possible solution: restrict the language
 - Mixins: explicit linearization, no relationships between mixins
 - Traits: no state, only methods
 - Our goal: can we solve the problem with fewer language restrictions?

The Diamond Problem



- Occurs when a class inherits an ancestor through more than one path
- Should InputOutputStream have multiple copies of Stream's instance variables, or just one?
 - Problem 1: if only one copy, how do we initialize InputOutputStream properly?
- Problem 2: how to perform modular typechecking of external methods/multimethods?

Problem 2: Typechecking External Methods



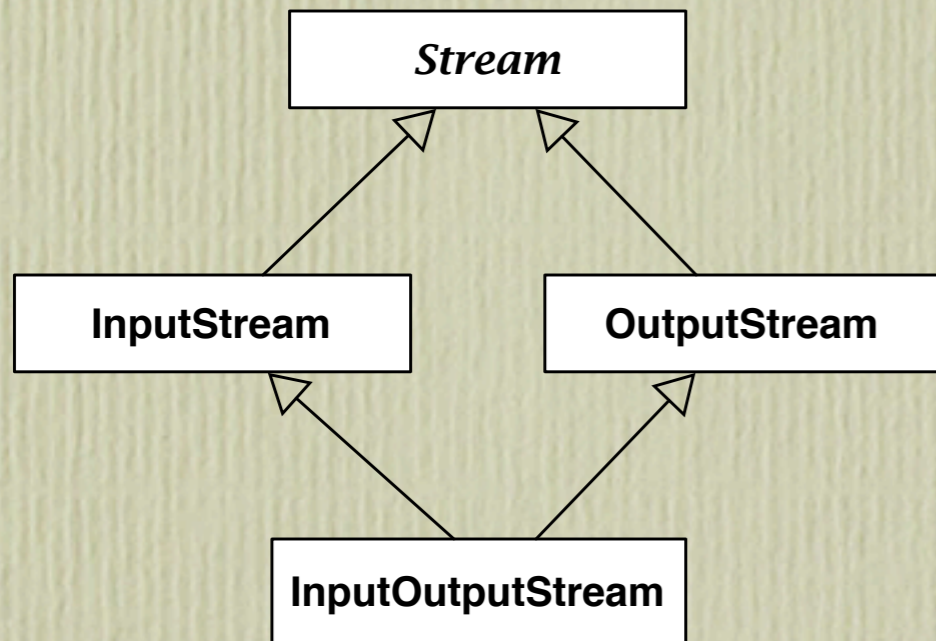
```
void Stream.seek(long pos) { }
```

```
void InputStream.seek(long pos) { ... }
```

```
void OutputStream.seek(long pos) { ... }
```

- External method:
 - like ordinary method, but can be defined outside class definition
 - performs *dispatch* on objects of that class's type
 - i.e., correct method selected based on run-time type
- Eliminates need for Visitor pattern

Problem 2: Typechecking External Methods



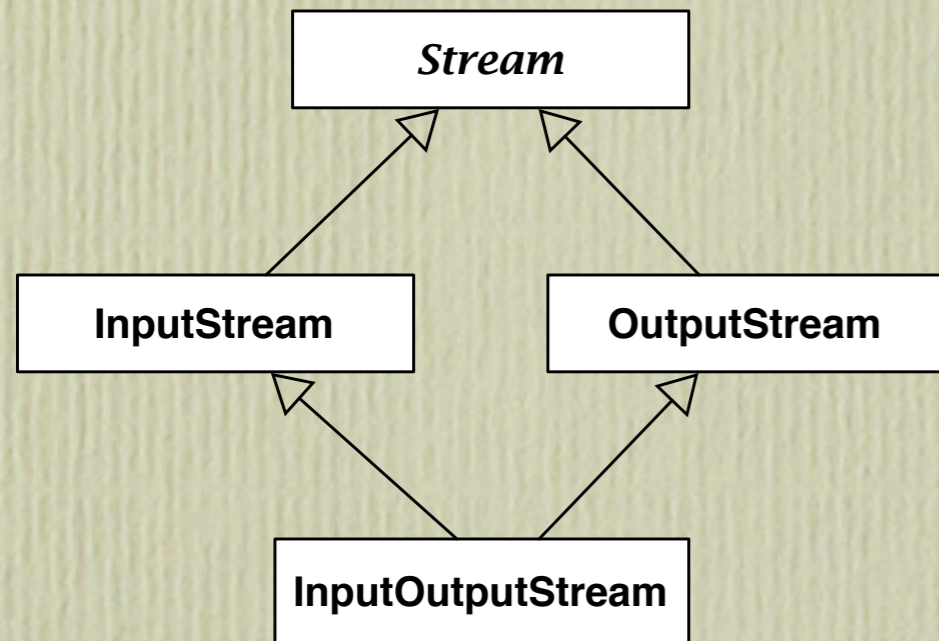
```
void Stream.seek(long pos) { }
```

```
void InputStream.seek(long pos) { ... }
```

```
void OutputStream.seek(long pos) { ... }
```

- What if we call `new InputStreamOutputStream().seek()`?
- How to modularly determine that this is ambiguous?
 - When checking `InputStreamOutputStream`, can't look for potentially ambiguous external method definitions
 - When checking `seek()`, can't look for diamonds in the class hierarchy

Problem 2: Typechecking External Methods



```
void Stream.seek(long pos) { }
```

```
void InputStream.seek(long pos) { ... }
```

```
void OutputStream.seek(long pos) { ... }
```

- Problem arises with any form of multiple inheritance:
 - Java-style
 - Dispatch on interfaces (JPred)
 - Traits
 - Dispatch on traits (Fortress)

Solution

- Disallow inheritance diamonds
- But, what if we need to define them?

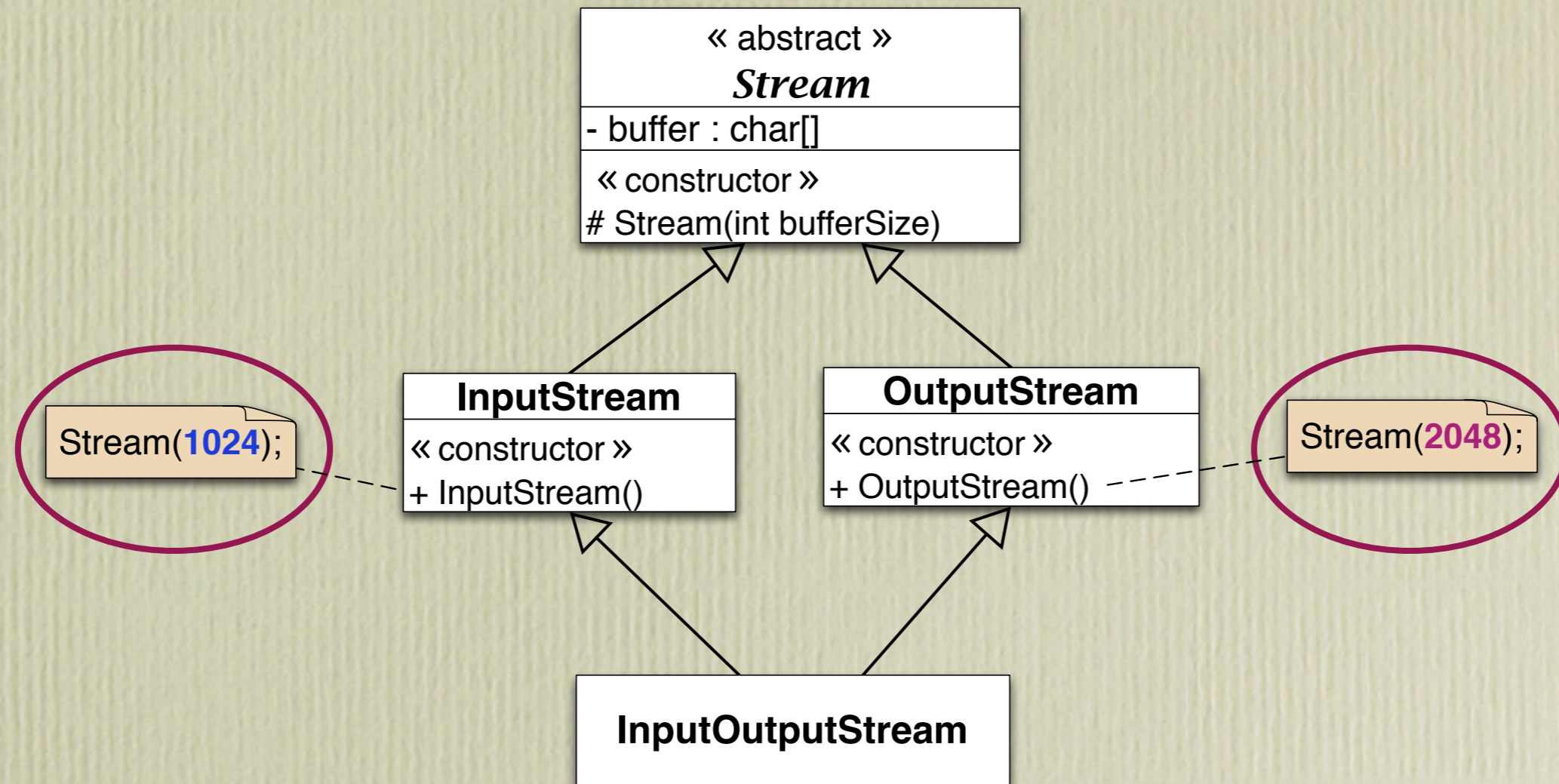
When an inheritance (subclass) diamond is *needed*:

- Use `requires` instead (generalization of a Scala construct)
- Captures notion of inheritance dependency
- If A requires B
 - A is a *subtype* of B (but not a *subclass*)
 - A is abstract
 - Concrete subclasses of A must extend B

CZ Design

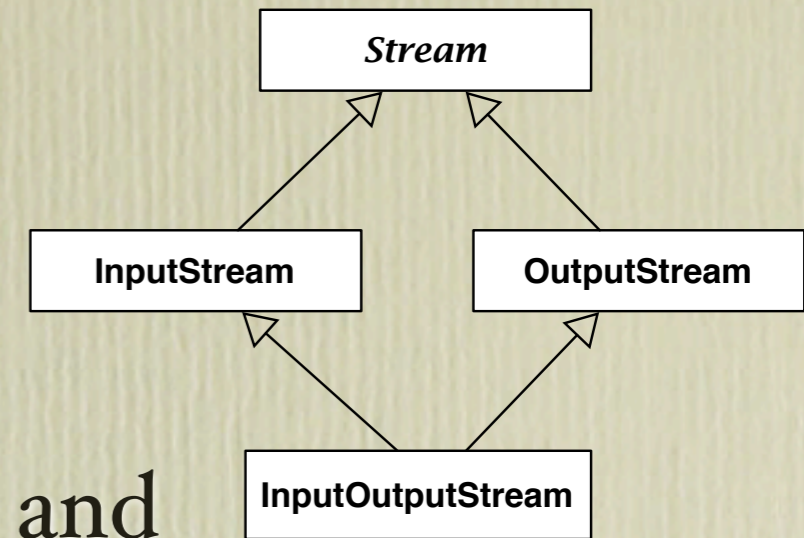
- Disallow inheritance diamonds
- When needed, use `requires` instead
 - Expresses inheritance dependency and provides subtyping

Problem 1: Object Initialization



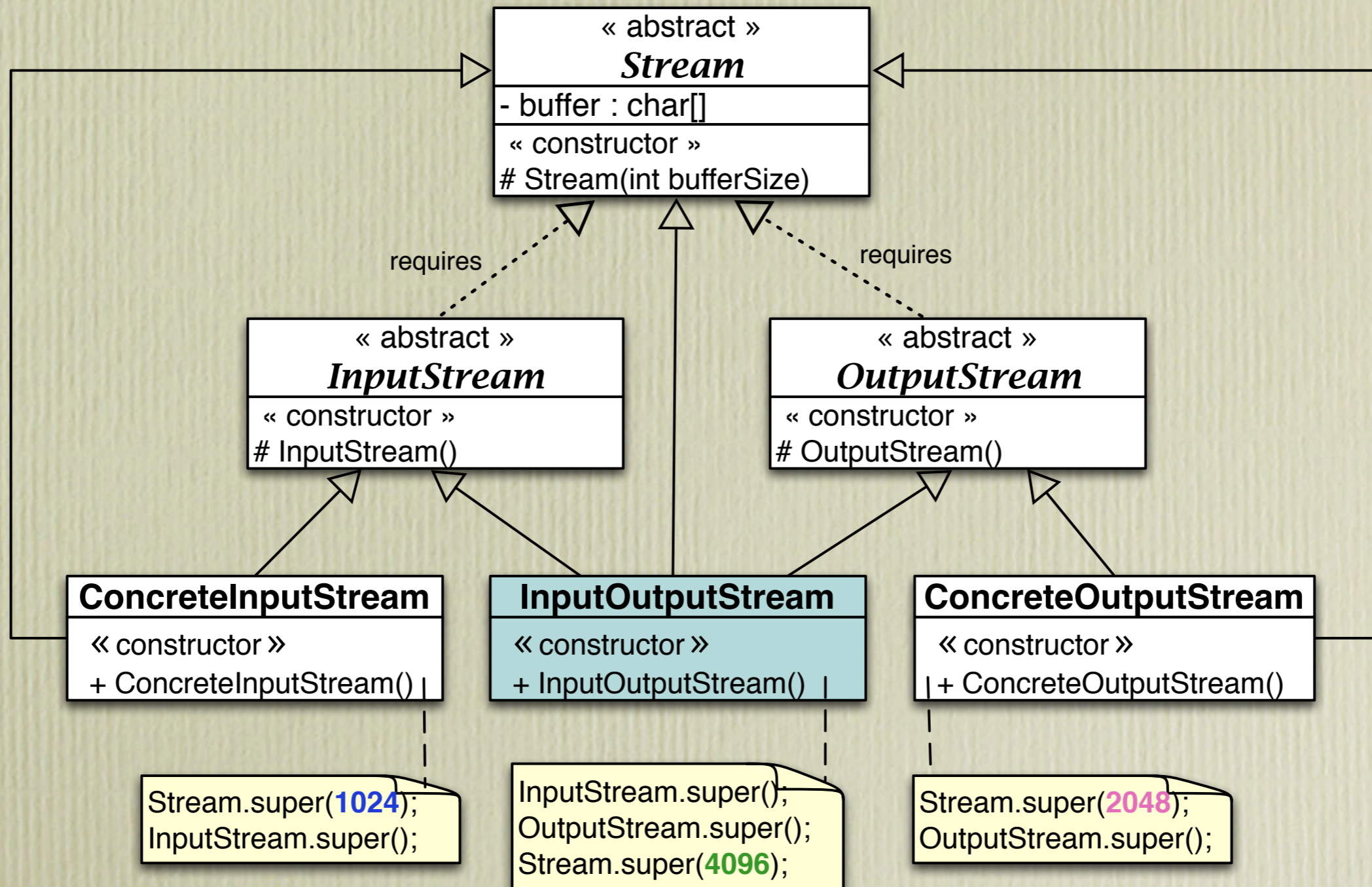
When initializing `InputStream`, How many times and with which argument is `Stream` constructor called?

Problem 1: Previous Solutions



- Eiffel, Stateful traits: call `InputStream` and `OutputStream` constructors explicitly; `Stream` constructor is called twice
 - What if `Stream()` performs a stateful operation?
- C++: call `Stream()` directly from `InputStream` and ignore other calls to `Stream()`
 - What if the ignored calls were important?
- Scala: trait constructors may not take parameters
 - Elegant, but restrictive

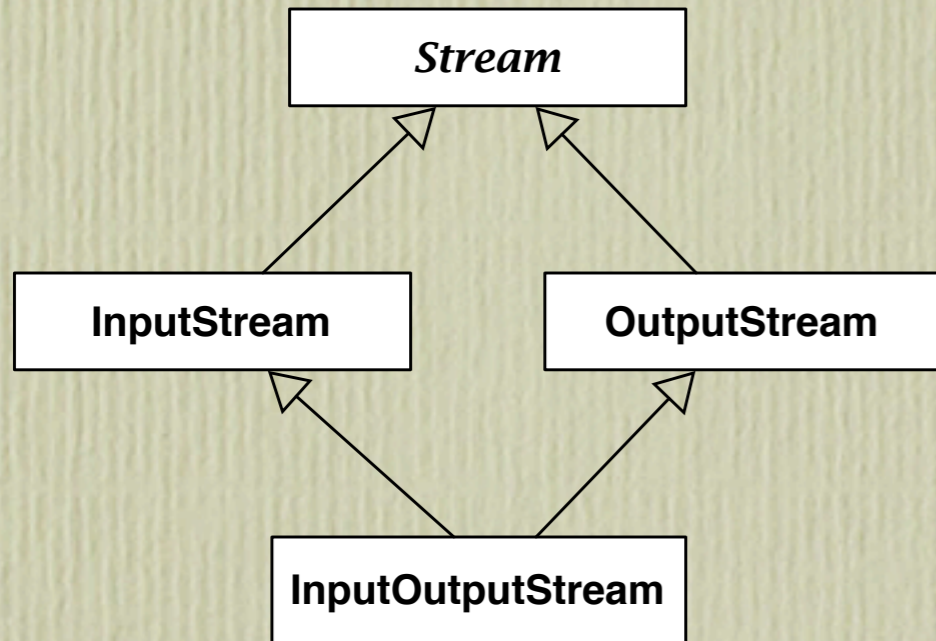
Problem 1: Streams in CZ



CZ Solves Problem 1

- No diamonds means:
 - graceful co-existence of state and multiple inheritance
 - No ignored constructor calls
 - No restrictions on constructors
 - Correct initialization semantics

Recall Problem 2: Typechecking External Methods



```
void Stream.seek(long pos) { }
```

```
void InputStream.seek(long pos) { ... }
```

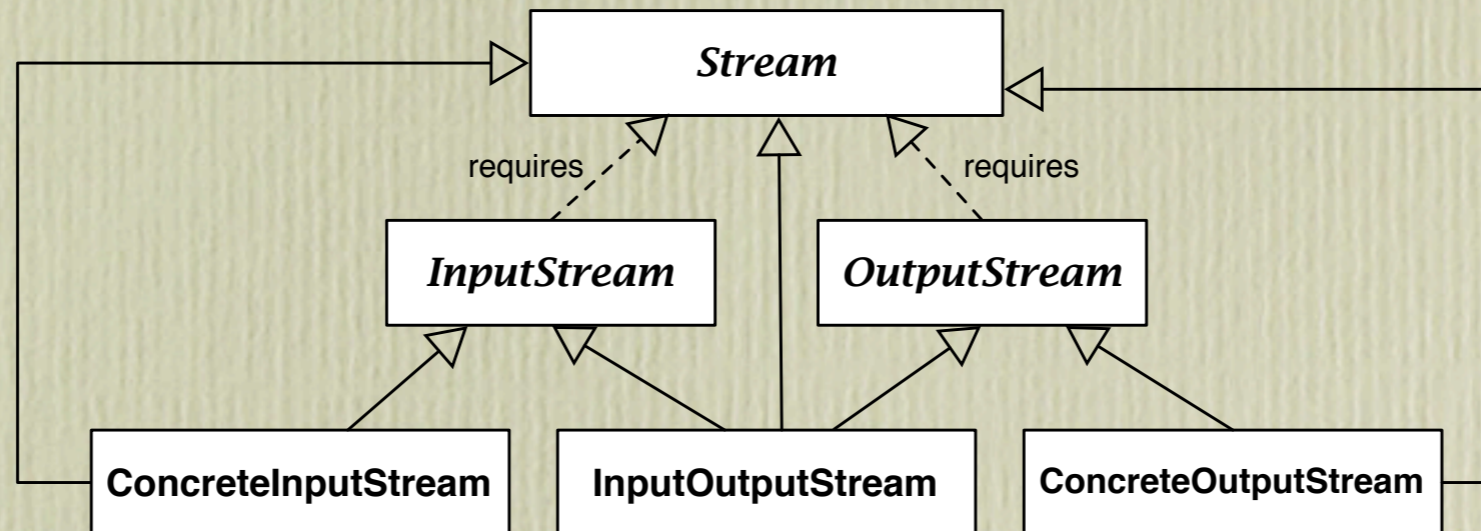
```
void OutputStream.seek(long pos) { ... }
```

- What if we call `new InputStreamOutputStream().seek()`?
- How to modularly determine that this is ambiguous?

Problem 2: Previous Solutions

- Disallow multiple inheritance across module boundaries (Dubious language)
- Require disambiguating methods for *every subset of incomparable types* (JPred, Fortress)
 - `void (InputStream && OutputStream).seek() { ... }`
- Even if type like `InputOutputStream` is never created
- Exponential in the number of incomparable types
 - **3** incomparable types => **4** additional methods
 - **4** incomparable types => **11** additional methods
 - **5** incomparable types => **26** additional methods

Problem 2: Typechecking external methods



- External override based on inheritance (subclassing)

```
Stream.seek(int pos) { ... }
```

```
ConcreteInputStream.seek(int pos) { ... }
```

```
ConcreteOutputStream.seek(int pos) { ... }
```

```
InputOutputStream.seek(int pos) { ... }
```

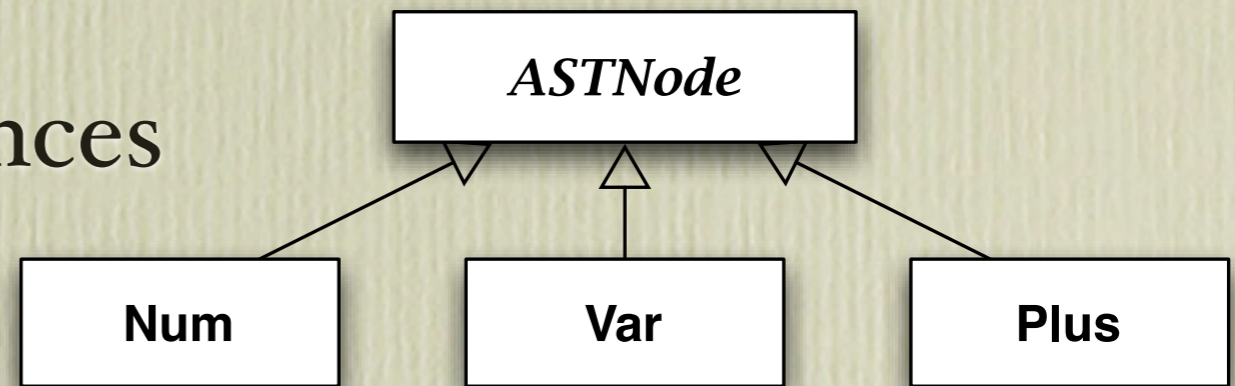
CZ Solves Problem 2

- No diamonds means
 - Ambiguity checking becomes easy
 - No manual disambiguation required

When to use requires rather than extends

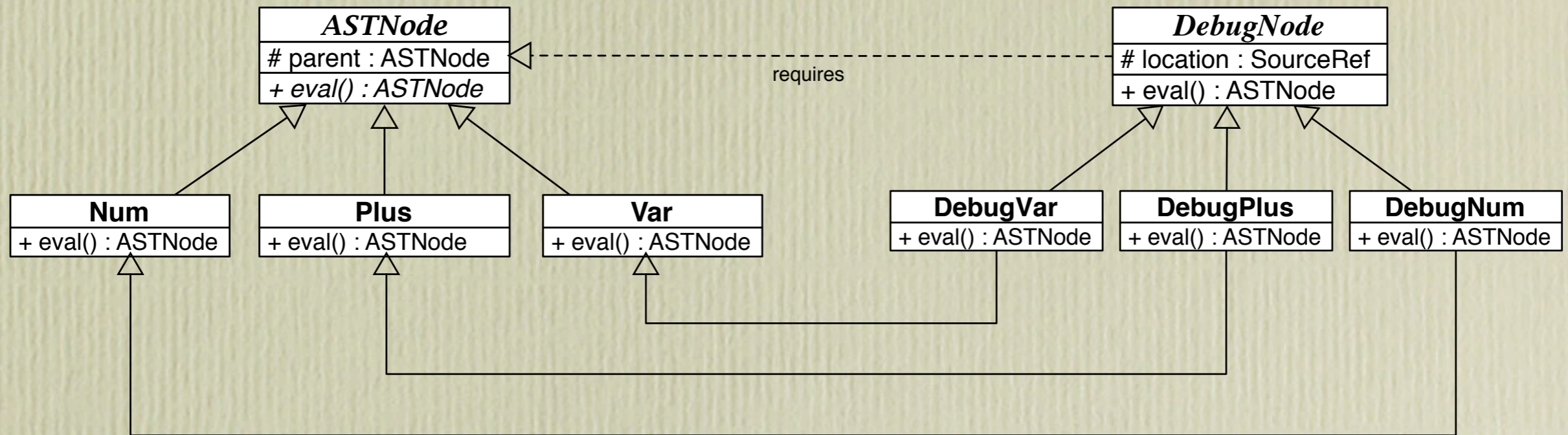
- Observe that a class serves two roles:

- Generator of instances
- Unit of reuse



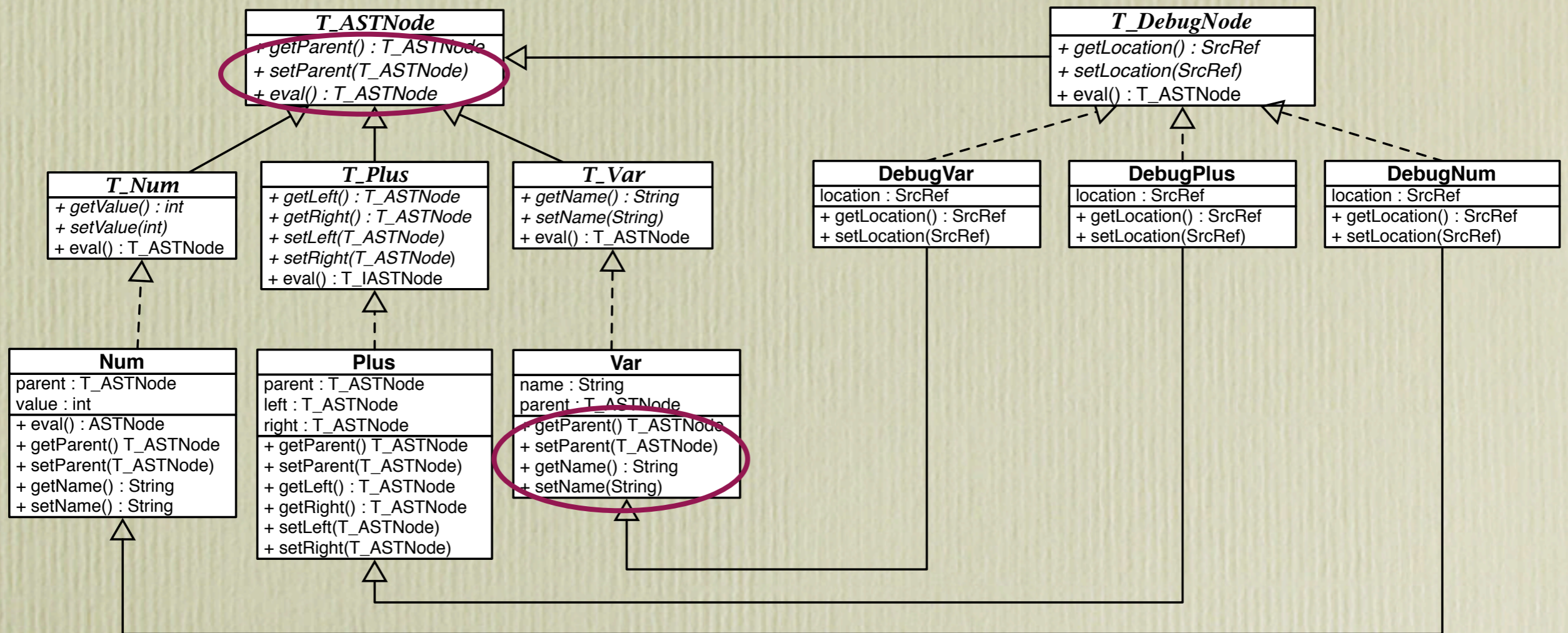
- If *A* is an extension of *B*, and is intended to be reused => use requires
(e.g. `InputStream` requires `Stream`)
- When subclasses of *A* are disjoint, use extends
(e.g. can have no subclass of `Num` and `Var`)

Example: Abstract Syntax Trees



```
void ASTNode.defCheck() { ... }  
void Var.defCheck()    { ... }  
void Plus.defCheck()   { ... }  
void Num.defCheck()    { ... }
```


Alternative Design: Traits



- How to define “state” that is private to a trait?
- Can only define public and protected accessors

Advantages of the design

- Allow reuse of both methods *and* state
- Capture design intent through requires
- Allows subtyping without inheritance
- Can typecheck external methods in a straightforward, modular way

CZ Status

- Language formalized, extension of Featherweight Java
 - Proved sound, shown to be modular
- Designed an extension of Java that provides (no-diamond) multiple inheritance and requires
 - Implemented typechecker (using JastAdd)

Related Work

- Stateful traits: Bergel et al. [CLSS '05]
- Scala: Odersky and Zenger [OOPSLA '05]
Odersky [tech report]
- Dubious: Millstein and Chambers, [I&C '02]
- JPred: Millstein et al [FOOL '06, TOPLAS '09]
- Fortress: Allen et al. [SAC '07]

Summary

- CZ takes a novel approach to the diamond problem
- Less restrictive than other solutions
- Allows multiple inheritance to co-exist with
 - State and initialization
 - Modular typechecking of multiple dispatch