MASKED TYPES for Sound Object Initialization

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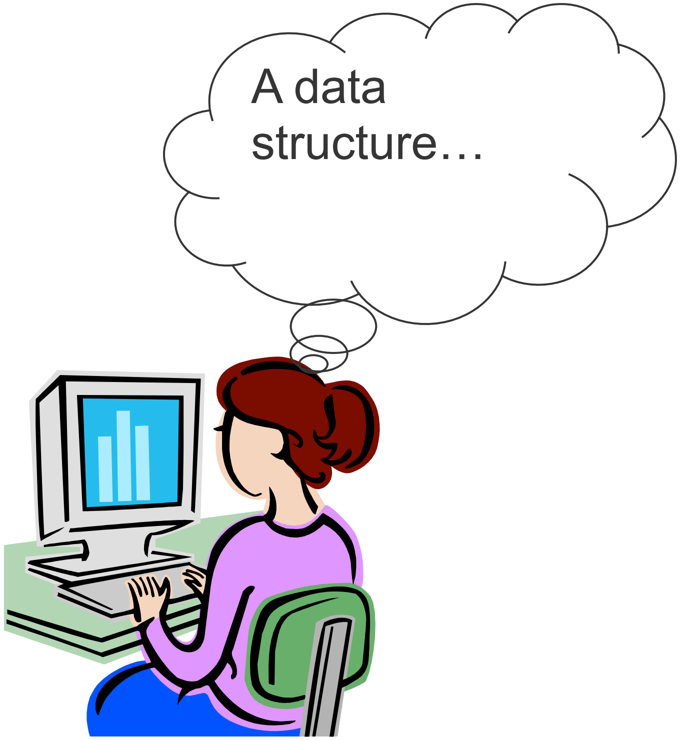
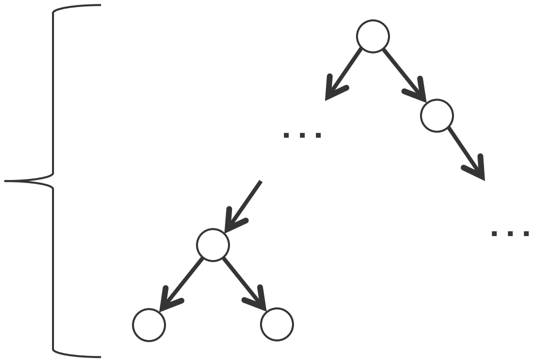
Fix the initialization problem

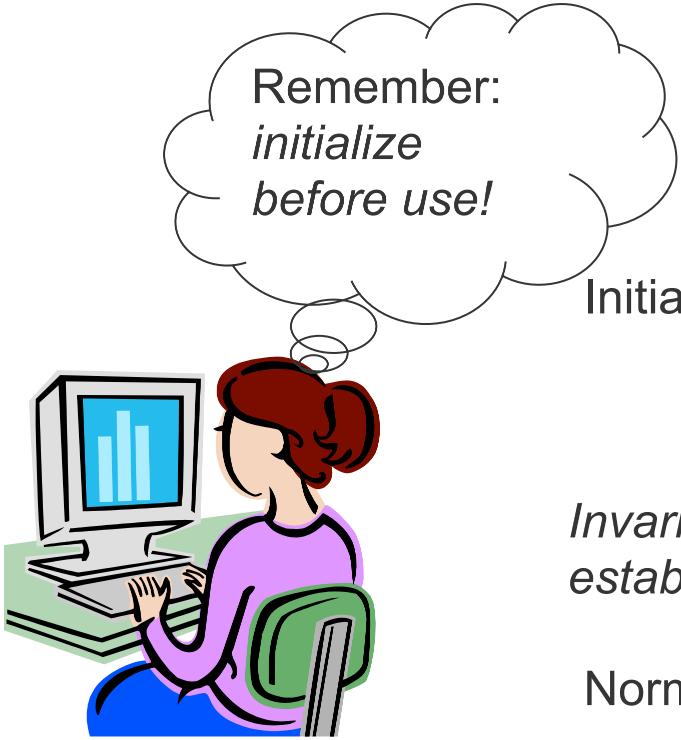
- Current mechanisms for object initialization are unsound
- This talk: a lightweight type system for sound initialization
  - Gets rid of null-pointer exceptions
  - Handles inheritance and cycles
- Implementation – J\mask

Alice wants a data structure…

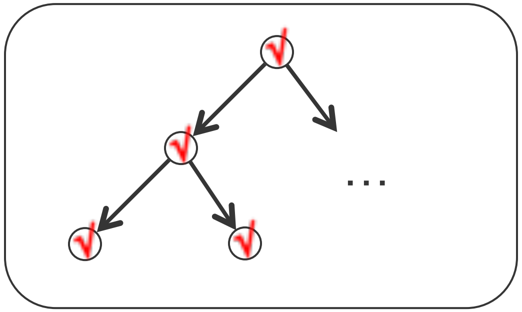




Alice wants a data structure…



Initialization



Invariants established

Normal use

No access to uninitialized data

- This methodology does not work!

An example with inheritance

```
class Point {
  int x, y;
  Point(int x, int y) {
    this.x = x;
    this.y = y;
    display();
  }
  void display() {
    System.out.println(x + “ “ + y);
  }
}

class CPoint extends Point {
  Color c;
  CPoint(int x, int y, Color c) {
    super(x, y);
    this.c = c;
  }
  void display() {
    System.out.println(x + “ “ + y + “ “ + c.name());
  }
}
```

Super constructor

Virtual method call

Field c not initialized yet!

A bug with no one to blame

```
class Point {
  int x, y;
  Point(int x, int y) {
    this.x = x;
    this.y = y;
    display();
  }
  void display() {
    System.out.println(x + “ “ + y);
  }
}
```

```
class CPoint extends Point {
  Color c;
  CPoint(int x, int y, Color c) {
    super(x, y);
    this.c = c;
  }
  void display() {
    System.out.println(x + “ “ + y + “ “ + c.name());
  }
}
```

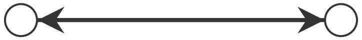
- Each individual class looks OK
- Classes don’t agree on the initialization contract

Unsound initialization

- Problem: initialization is *unsound*:
  - Can read uninitialized object fields
- "Solution" (Java/C#): fields pre-initialized with default "null" values
  - Null is a value of all object types
  - Ubiquitous null checks and possible null-pointer exceptions
- Result: unreliable software

Current language support

- Object-oriented initialization is unsound
  - Inheritance
  - Cyclic data structures



- Functional languages trade expressiveness for soundness
  - Cyclic data structures need encoding/refs

MASKED TYPES

- T \ f
  - Base type T
  - *Field mask* on f
    - Possibly uninitialized
    - Not readable
- Assignments remove masks

```
// x : CPoint \ c
x.c = new Color(“Blue”);
// x : CPoint
```

- Typestates

More masks

- T \ *
  - Disallows reading any field
- Point \ Point.sub
  - Disallows reading fields declared in subclasses
  - Point \ * = Point \ x \ y \ Point.sub
- Abstract masks for data abstraction

Inheritance

- Make initialization contracts explicit
- Methods and constructors have *mask effects*
  - Capture initialization contracts
  - Support modular type-checking

Back to the example

Point \ x \ y \ Point.sub → Point \ *

Point \ y \ Point.sub →

Point \ Point.sub →

```
class Point {
  int x, y;
  Point(int x, int y) effect * -> Point.sub {
    this.x = x;
    this.y = y;
    display();
  }
  void display() effect {} -> {} {
    System.out.println(x + “ “ + y);
  }
}

class CPoint extends Point {
  Color c;
  CPoint(int x, int y, Color c) {
    super(x, y);
    this.c = c;
  }
  void display() {
    System.out.println(x + “ “ + y + “ “ + c.name());
  }
}
```

- If we blame the Point class, …

Back to the example

```
class Point {
  int x, y;
  Point(int x, int y) effect * -> Point.sub {
    this.x = x;
    this.y = y;
    display();
  }
  void display() effect {} -> {} {
    System.out.println(x + “ “ + y);
  }
}

class CPoint extends Point {
  Color c;
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    super(x, y);
    this.c = c;
  }
  void display() {
    System.out.println(x + “ “ + y + “ “ + c.name());
  }
}
```

Point \ Point.sub →

Method call disallowed!

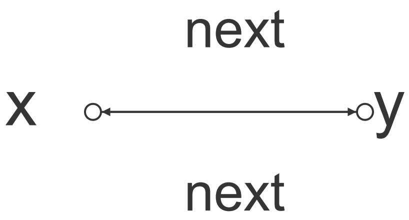
- If we blame the Point class, …
- Compiler inserts default effects

Cyclic data structures

- Cyclic data structures are common
  - Doubly-linked lists
  - Circular lists
  - Binary trees with parent pointers
- Sound initialization is challenging
  - Disallow reading fields pointing to "incomplete" objects
  - Know when initialization completes

An example

```
class Node {
   Node next;
}
Node x = new Node();
Node y = new Node();
x.next = y;
…
y.next = x;
```



y.next uninitialized
⇒ not safe to read x.next

“ties the knot”
⇒ both objects are safe to use

- Conditional masks
  - Dependencies between masks
  - Graph theory-based type checking

An example

```
class Node {
   Node next;
}
Node x = new Node();
Node y = new Node();
x.next = y;
…
y.next = x;
```

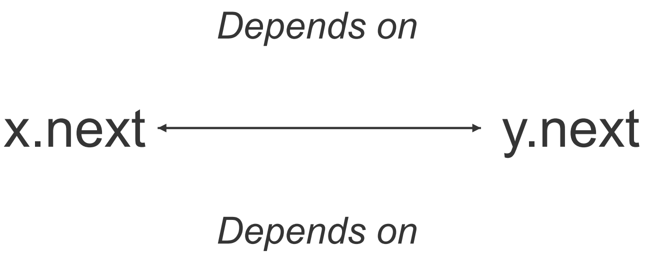
Conditionally masked type

x : Node \ next[y.next]

x : Node \ next[y.next]
y : Node \ next[x.next]

Removal of circular dependencies

x : Node
y : Node



J\mask calculus

- Object calculus with heap
  - No special value “null”
  - Uninitialized fields cannot be read
- Object initialization is sound
  - Evaluation never gets stuck
  - Proof:
    - Encoding of graph theoretical problems
    - progress + preservation

J\mask language

- Constructors not special
- Default effects reduce annotation burden
- Implementation
  - Polyglot compiler framework (Nystrom, Clarkson & Myers 03)
  - Flow-sensitive type system
  - Translation to Java by type erasure

Experience

- Java Collections Framework (1.4.2)
  - LinkedList, ArrayList, HashMap, TreeMap, Stack, …
  - 29 source files, 18,000 LOC
- Results
  - Handled JCF initialization patterns
  - Removed nulls for initialization
  - Low annotation burden
    - 11 explicit effects
    - 11 explicit masked types

Related work

- Non-null types
  - @NonNull annotations (Java 6/7)
  - Delayed types (Fähndrich & Xia 07)
- Typestates
  - Typestates for objects (DeLine & Fähndrich 04)
  - Heap monotonic typestates (Fähndrich & Leino 03)
- Static analysis
  - Detecting null-pointer exceptions (FindBugs)
  - Shape analysis

Summary

- Sound and expressive initialization
  - Handles inheritance and cycles
- Local, modular reasoning
  - Mask effects
  - Abstract masks
- Lightweight
  - Low annotation burden
    - No aliasing information
    - Default annotation
  - No run-time overhead
- Maybe the end of null-pointer exceptions!

MASKED TYPES

J\mask source code available at http://www.cs.cornell.edu/Projects/jmask/