DPJizer: A Tool for Automated Java to DPJ Transformation

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An Effect System

```
public FileWriter(String)
throws IOException
```


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Effect Systems

- Effect systems are important for reasoning about side effects.
- Effects are enforceable contracts.
- Effects are machine-checkable documentation.
- Effect system enable composability and modular reasoning.

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Effect Systems for Parallel Programming

- Effects systems can be used to reason about correctness of parallel programs.
- **DPJ** = Deterministic Parallel Java

DPJ Effect System

- A **region** is a name for a collection of locations.
- An **effect** is a **read** or **write** operation on a region.
- Compiler checks that parallel tasks are **noninterfering**.

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Region and Effect

- Programmer assigns regions to fields.
- Programmer summarizes effects of method bodies.

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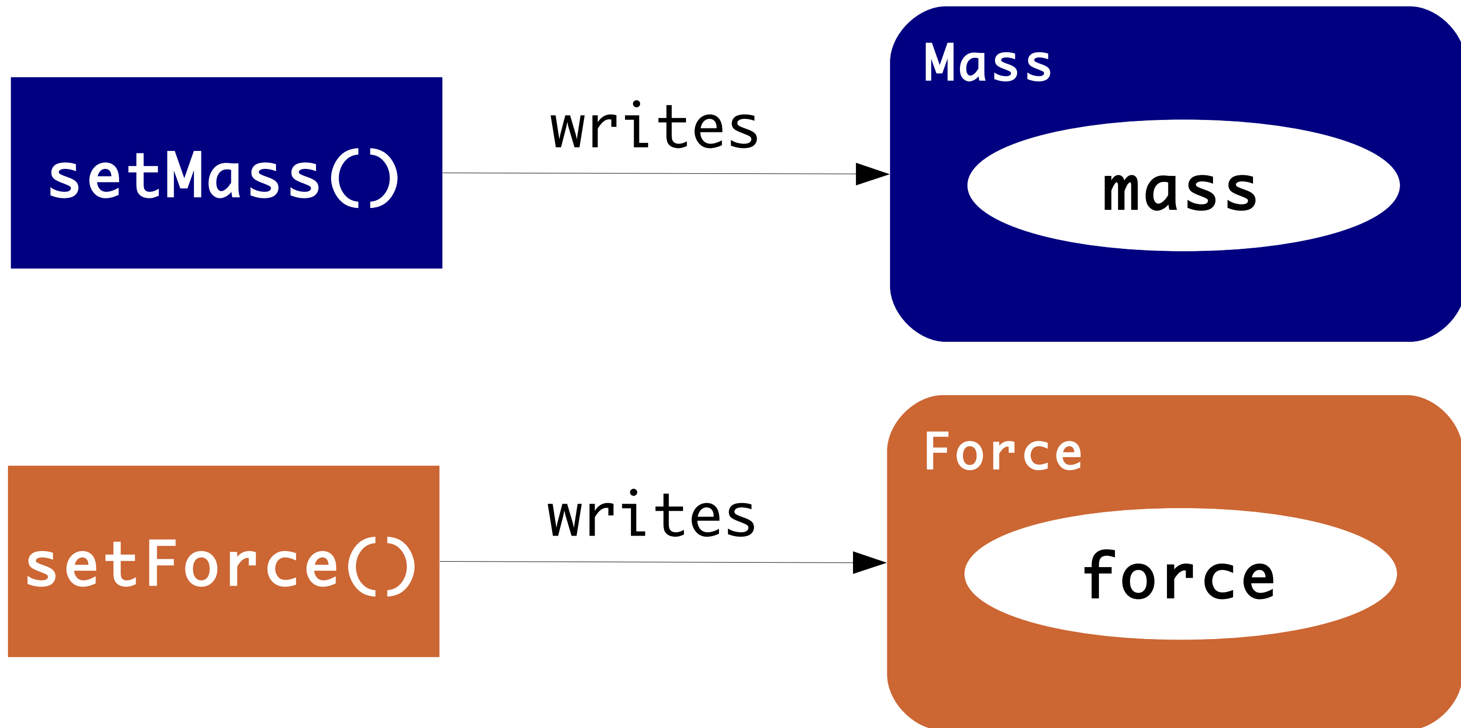
```
double mass in Mass;
double force in Force;
setMass(double) writes Mass;
setForce(double) writes Force;
```



Why have not effect systems taken off yet?

- Writing annotations manually is **error-prone** and **tedious**.
- Whenever the code changes annotations have to be updated.
- On average, programmers annotate **8%** of lines of DPJ source code.

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DPJizer

- DPJizer makes effect systems practical.
- DPJizer infers a summary of effects for each method.

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DPJizer Preview Dialog

Changes to be performed

Infer Effects

BinaryTree.java - TestProject/dpj-programs/01-flat-regions

BinaryTree.java

Original Source

```
1 public class BinaryTree {
2   region L, R, M;
3   BinaryTree left in L;
4   BinaryTree right in R;
5   double mass in M;
6
7   void setMass(double mass) {
8     this.mass = mass;
9     initTree();
10  }
11
12  void initTree() {
13    left = new BinaryTree();
14    right = new BinaryTree();
15  }
```

Refactored Source

```
1 public class BinaryTree {
2   region L, R, M;
3   BinaryTree left in L;
4   BinaryTree right in R;
5   double mass in M;
6
7   void setMass(double mass) writes Root : BinaryTree.L, Root : BinaryTree.M, Root : BinaryTree.R {
8     this.mass = mass;
9     initTree();
10  }
11
12  void initTree() writes Root : BinaryTree.L, Root : BinaryTree.R {
13    left = new BinaryTree();
14    right = new BinaryTree();
15  }
```

Preview > | OK | Cancel

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Highlight Source of Effects

```
void setMass(double mass)
                    writes Root : BinaryTree.M,
                    Root : BinaryTree.L,
                    Root : BinaryTree.R {
   this.mass = mass;
   initTree();
}
```


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Region Names Ex. (1/2)

```
class Node {
    region Mass, Force;
    double mass in Mass;
    double force in Force;

    void setMass(double mass) writes Mass {
        this.mass = mass; // Effect: writes Mass
    }

    void setForce(double force) writes Force {
        this.force = force; // Effect: writes Force
    }
```


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Region Names Ex. (2/2)

```
    void initialize(double mass, double force)
     writes Mass, Force {
        cobegin {
            this.setMass(mass); // Effect: writes Mass
            this.setForce(force); // Effect: writes Force
        }
    }
}
```

Input: DPJ Program Annotated with Region Information

DPJizer

Constraint Generator

Constraints: reads, writes, and invokes

Constraint Solver

Output: DPJ Program with Region and Effect Annotations

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Constraints in Region Names Ex. (1/2)

```
class Node {
    region Mass, Force;
    double mass in Mass;
    double force in Force;

    void setMass(double mass) {
        this.mass = mass; // Constraint: writes Mass
    }

    void setForce(double force) {
        this.force = force; // Constraint: writes Force
    }
```

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Constraints in Region Names Ex. (2/2)

```
void initialize(double mass, double force) {
    cobegin {
        // Constraint: invokes setMass()
        this.setMass(mass);

        // Constraint: invokes setForce()
        this.setForce(force);
    }
  }
}
```

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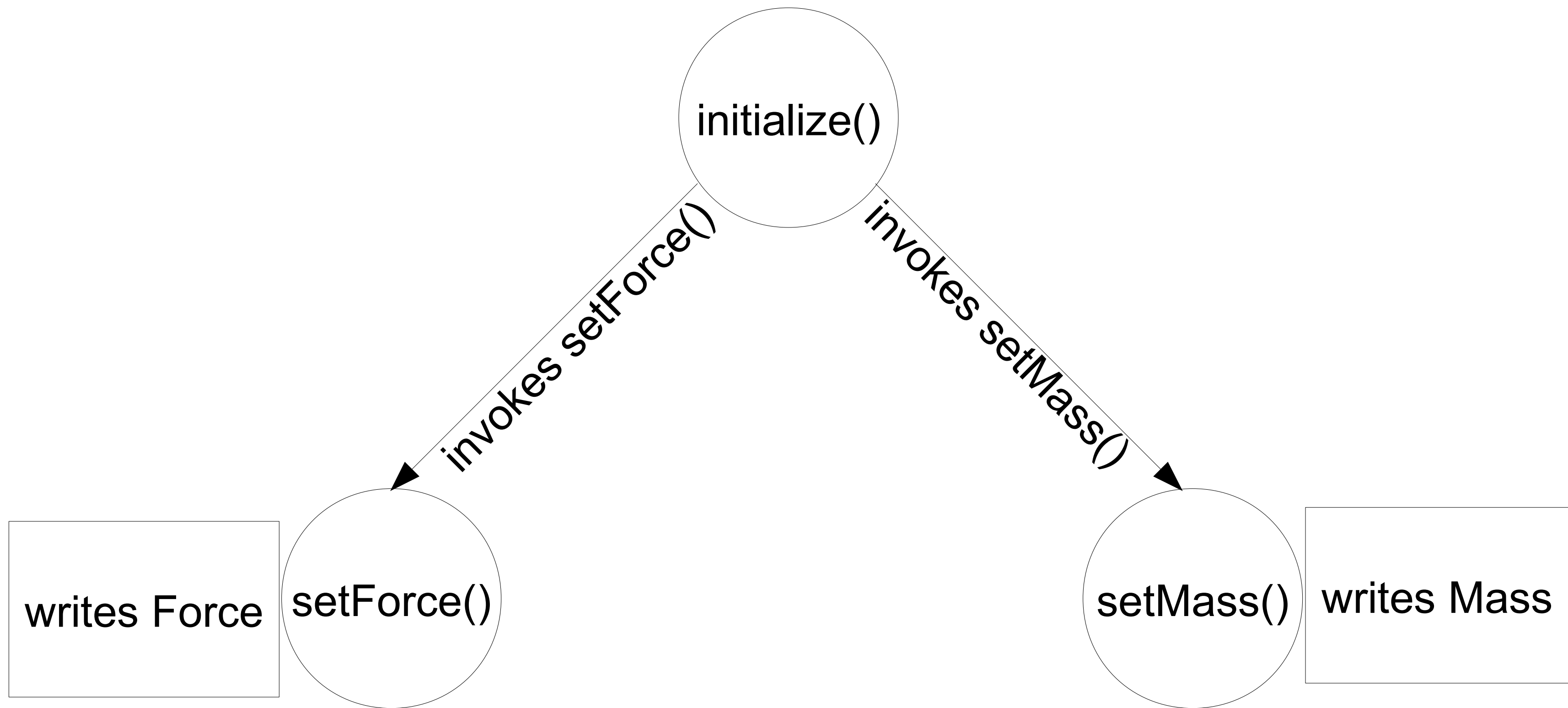
Constraint Generation Output



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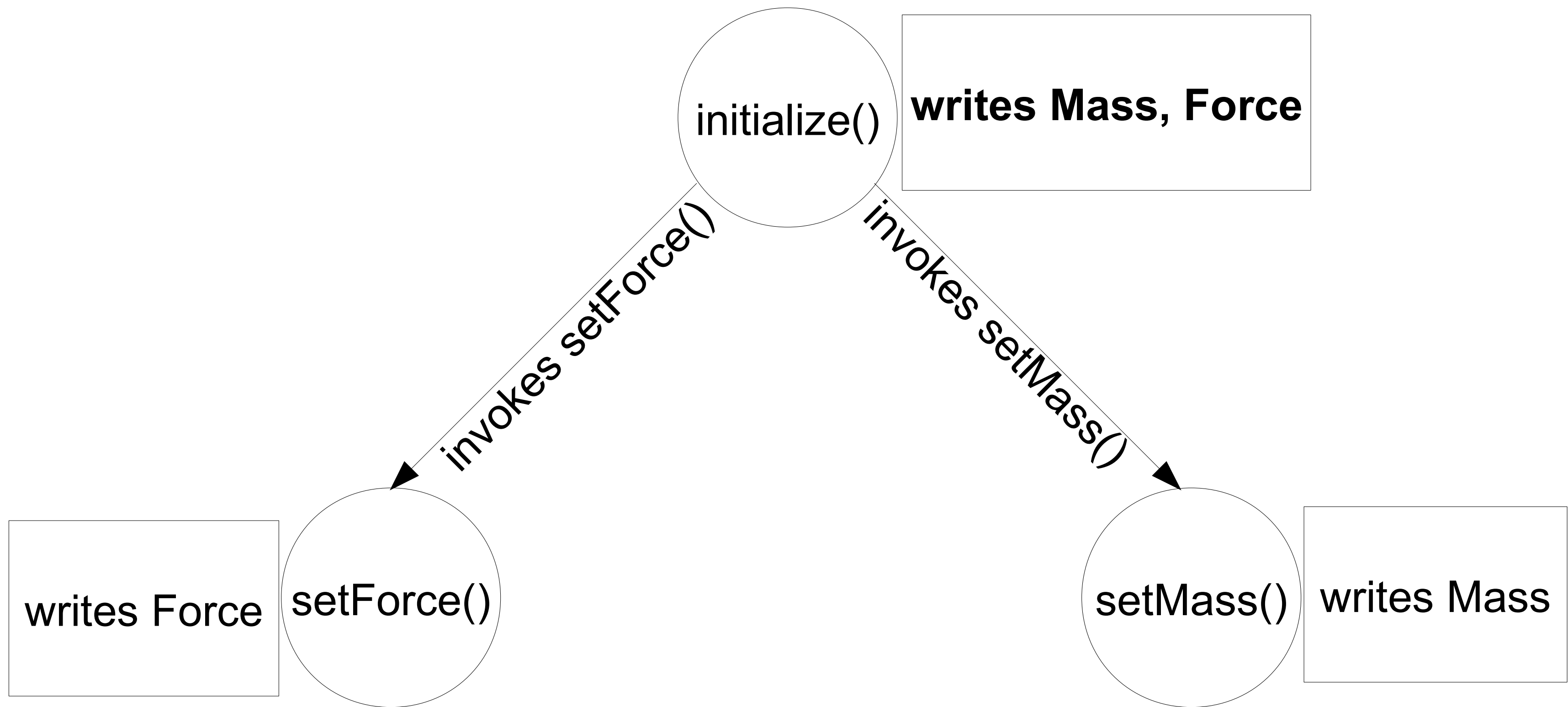
Constraint Solving



Region Parameters

- Region names distinguish different fields of an object.
- Region parameters distinguish different **object instances**.

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Region Parameters Ex. (1/6)

```
class Node<region P> {
    region L, R;
    double mass in P;
    Node<L> left in L;
    Node<R> right in R;
    //...
}
```

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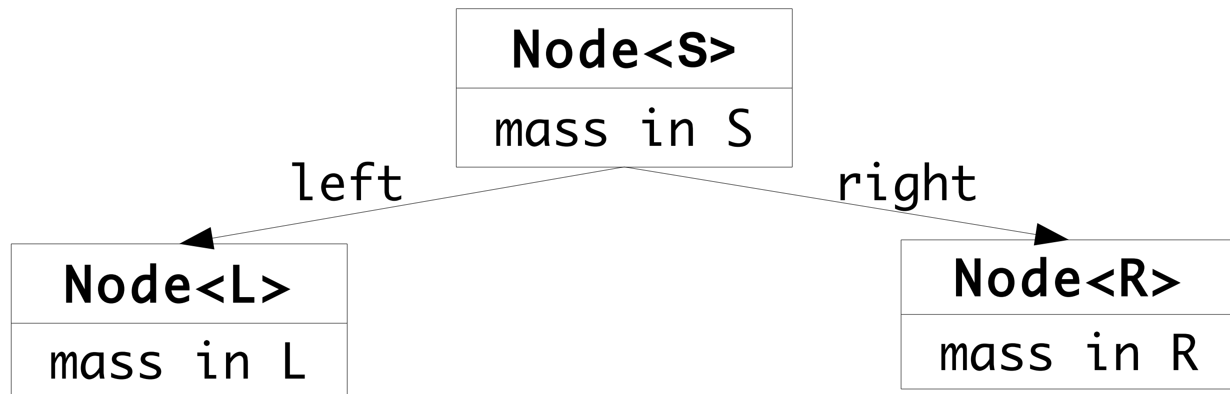
Region Parameters Ex. (2/6)

```
class Node<region P> {
    region L, R;
    double mass in P;
    Node<L> left in L;
    Node<R> right in R;
    //...
}
```



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Region Parameters Ex. (3/6)

```
class Node<region P> {
    region L, R;
    double mass in P;
    Node<L> left in L;
    Node<R> right in R;

    void setMass(double mass) {
        this.mass = mass;
    }
```

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Region Parameters Ex. (4/6)

```
class Node<region P> {
    region L, R;
    double mass in P;
    Node<L> left in L;
    Node<R> right in R;

    void setMass(double mass) writes P {
        this.mass = mass; // Effect: writes P
    }
```

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Region Parameters Ex. (5/6)

```
void setMassOfChildren(double mass) {
    cobegin {
        if (left != null) left.setMass(mass);

        if (right != null) right.setMass(mass);
    }
}
}
```

Region Parameters Ex. (6/6)

```
void setMassOfChildren(double mass) writes L, R {
    cobegin {
        // Effect: writes L
        if (left != null) left.setMass(mass);

        // Effect: writes R
        if (right != null) right.setMass(mass);
    }
  }
}
```


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Extending the Invokes Constraint

- The invokes constraint records region substitutions.
- `C<region P> { /* … */ }`
- `new C<R>().m()`
- `invokes m() where` **`{P → R}`**

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Constraints in Region Parameters Ex. (1/2)

```
class Node<region P> {
    region L, R;
    double mass in P;
    Node<L> left in L;
    Node<R> right in R;

    void setMass(double mass) {
        this.mass = mass; // Constraint: writes P
    }
```

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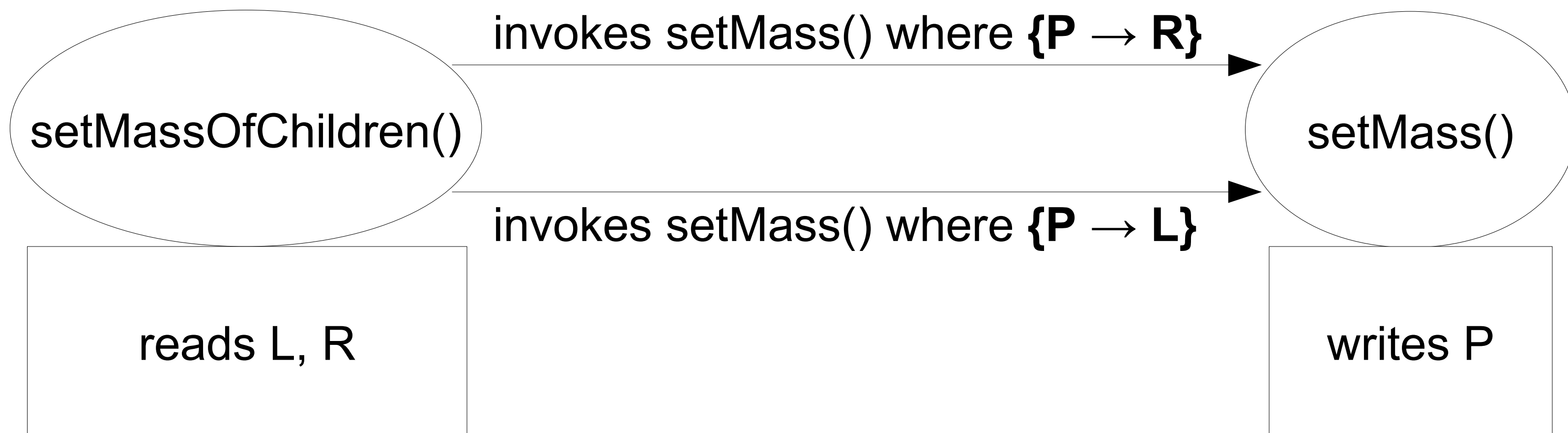
Constraints in Region Parameters Ex. (2/2)

```
void setMassOfChildren(double mass) {
    cobegin {
        // Constraint: reads L,
        //     invokes setMass() where {P → L}
        if (left != null) left.setMass(mass);

        // Constraint: reads R,
        //     invokes setMass() where {P → R}
        if (right != null) right.setMass(mass);
    }
}
}
```

Constraint Generation Output



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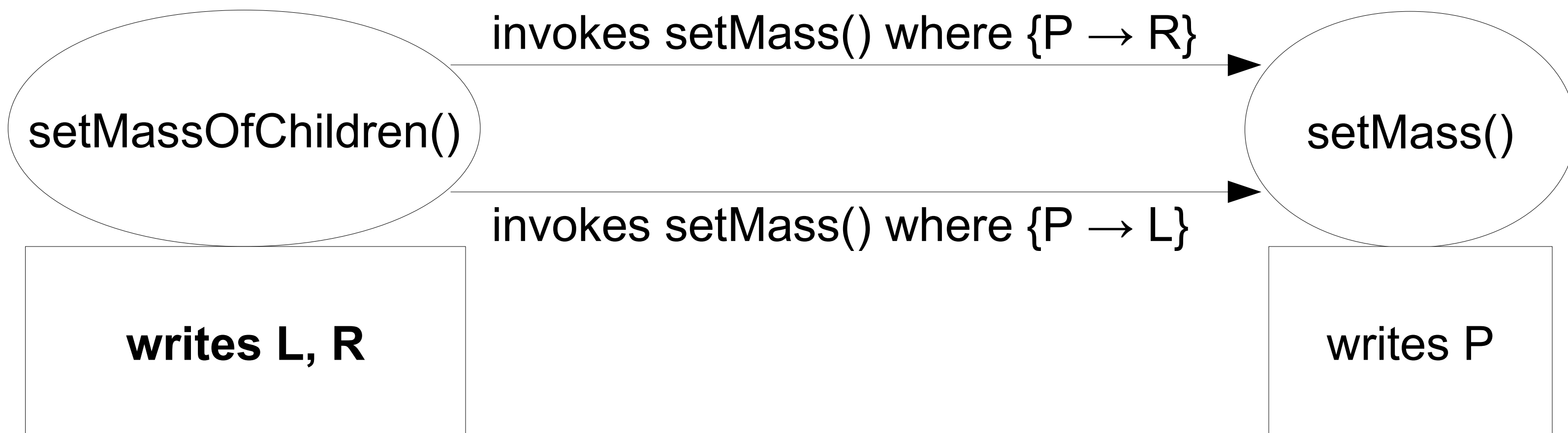
Constraint Solving



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Region Path Lists (RPLs)

- An RPL is a colon separated list of region names e.g. P : L : R : R
- $\{ P : R1 : R2, P : R3 \} \subseteq P : *$
- RPLs are useful to express tree-like recursive updates.

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RPL Ex.

```
class Node<region P> {
    region L, R;
    double mass in P;
    Node<P:L> left in P:L;
    Node<P:R> right in P:R;
}
```

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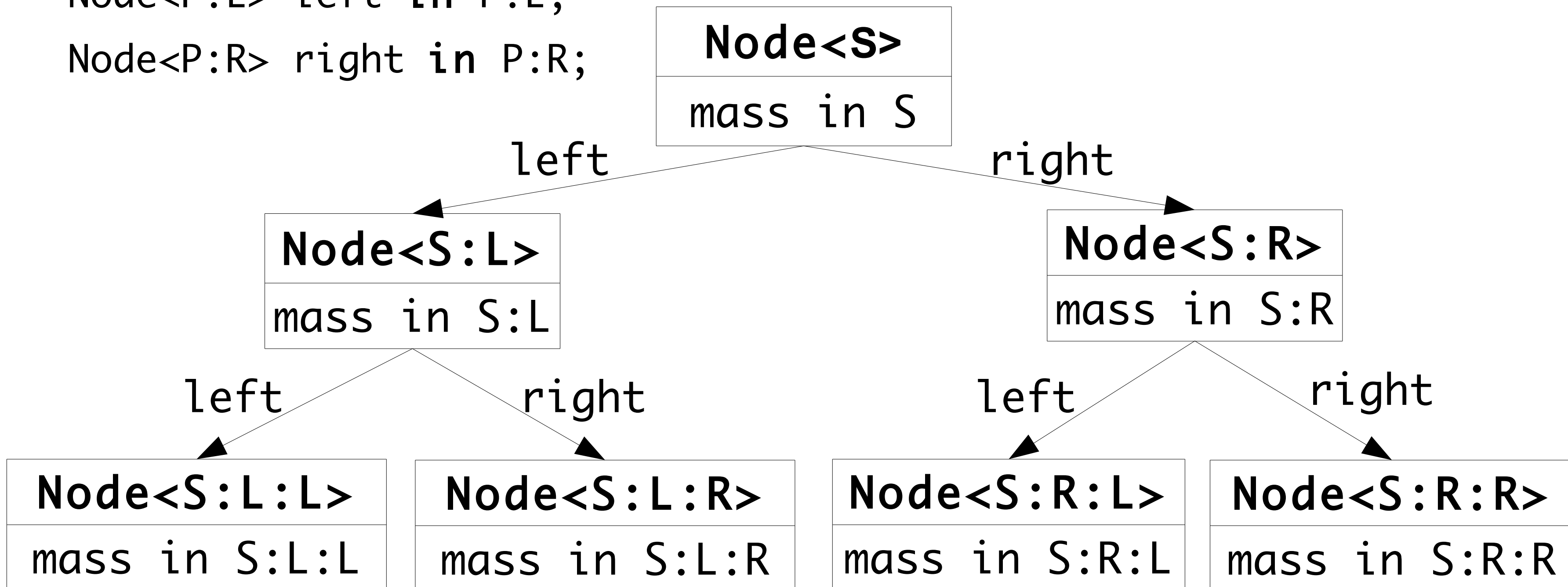
RPL Ex.

```
class Node<region P> {
     region L, R;
     double mass in P;
     Node<P:L> left in P:L;
     Node<P:R> right in P:R;
}
```



RPL Ex. (1/2)

```
class Node<region P> {
    region L, R;
    double mass in P;
    Node<P:L> left in P:L;
    Node<P:R> right in P:R;
    void setMassForTree(double mass) {
        this.mass = mass;
        cobegin {

            if (left != null) left.setMassForTree(mass);

            if (right != null) right.setMassForTree(mass);
        }
    }
}
```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RPL Ex. (2/2)

```
class Node<region P> {
    region L, R;
    double mass in P;
    Node<P:L> left in P:L;
    Node<P:R> right in P:R;
    void setMassForTree(double mass) writes P:* {
        this.mass = mass; // Effect: writes P
        cobegin {
            // Effect: writes P:L:*
            if (left != null) left.setMassForTree(mass);
            // Effect: writes P:R:*
            if (right != null) right.setMassForTree(mass);
        }
    }
}
```

Constraints in RPL Ex.

```
class Node<region P> {
    region L, R;
    double mass in P;
    Node<P:L> left in P:L;
    Node<P:R> right in P:R;
    void setMassForTree(double mass) {
        this.mass = mass; // Constraint: writes P
        cobegin {
    //Constraint:reads P:L,invokes setMassForTree where {P→ P:L}
            if (left != null) left.setMassForTree(mass);
    //Constraint:reads P:R,invokes setMassForTree where {P→ P:R}
            if (right != null) right.setMassForTree(mass);
        }
    }
}
```


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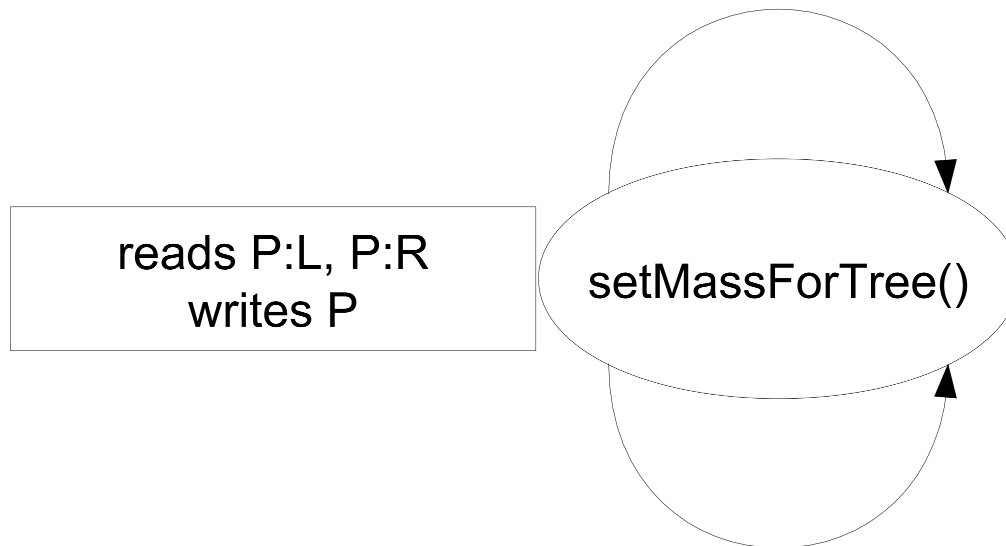
Constraint Generation Output



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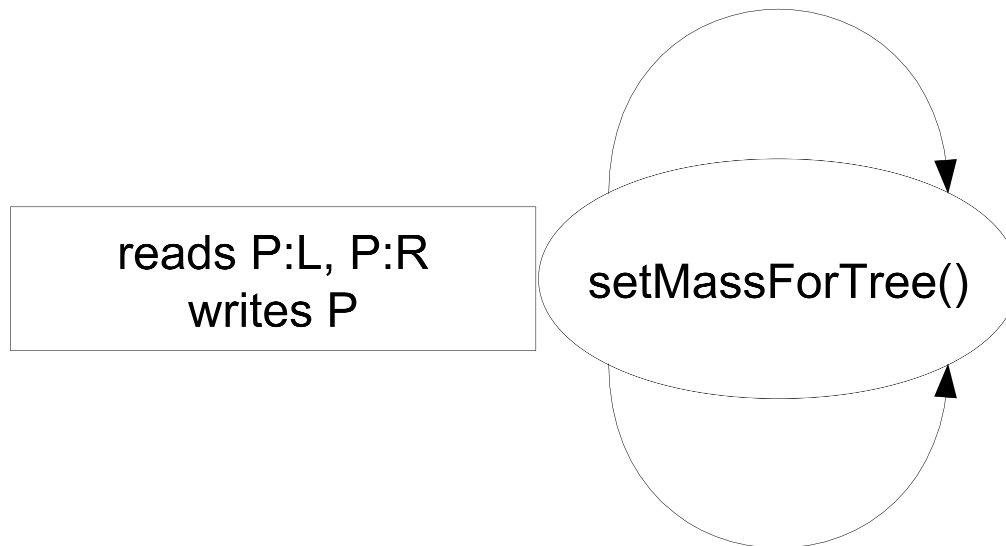
Constraint Solving



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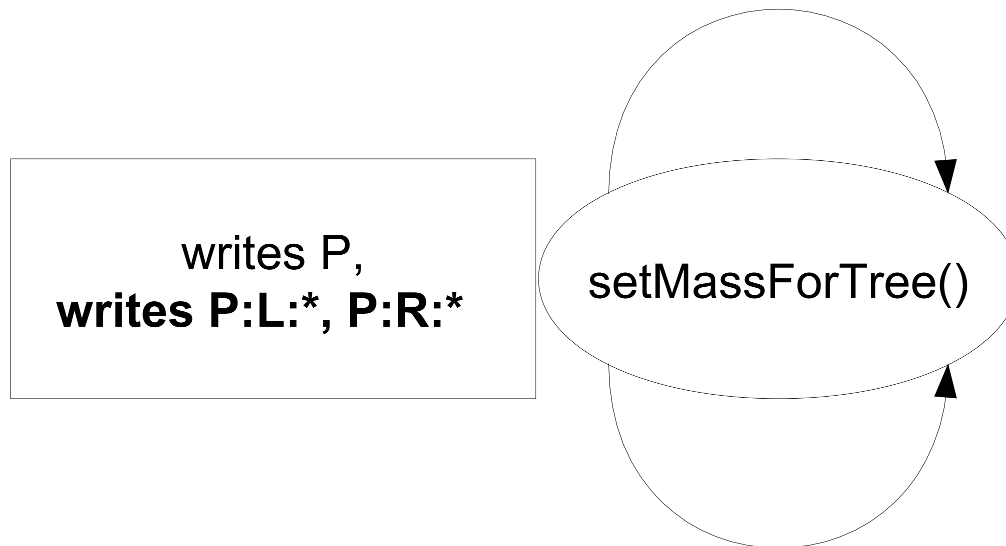
Constraint Solving



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Evaluation

- Research Questions
  - Is DPJizer useful?
    - Does it alleviate the burden of writing effect annotations?
  - Are the inferred effects precise?
    - Do the inferred effects enable the compiler to prove determinism of the program?

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Evaluation Methodology

- Quantitative
  - We compared the inferred effects to manual effects.
- Qualitative
  - We conducted a survey on DPJ programmers.

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Problems of Manual Effects

- It is **time consuming** to write the effects manually.
- Programmers might write **redundant** effects
  - e.g. reads P, writes P
- Programmer might write **coarse-grained** effects
  - e.g. writes P:* instead of writes P

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Comparing Manual to Inferred Effects

- We used DPJizer to infer method effect summaries of 11 programs.
  - Barnes-Hut, CollisionTree, IDEA, K-means, ListRanking, MergeSort, MonteCarlo, QuadTree, QuickSort, StringMatching, and SumReduce

Total SLOC	Total # of Manually Written Effects	Total # of Effects Too Coarse By Keyword	Total # of Effects Too Coarse By Region	Total # of Redundant Effects
5046	406	17	43	24

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Summary

- DPJizer is an interactive tool for inferring effect annotations given the region annotations.
- DPJizer infers effects that are sufficiently precise and fine-grained.
- We are working on analyses to infer most of the region annotations as well.

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