# State-copying and Recomputation in Parallel Constraint Programming with Global Constraints

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# Constraint Programming (CP)

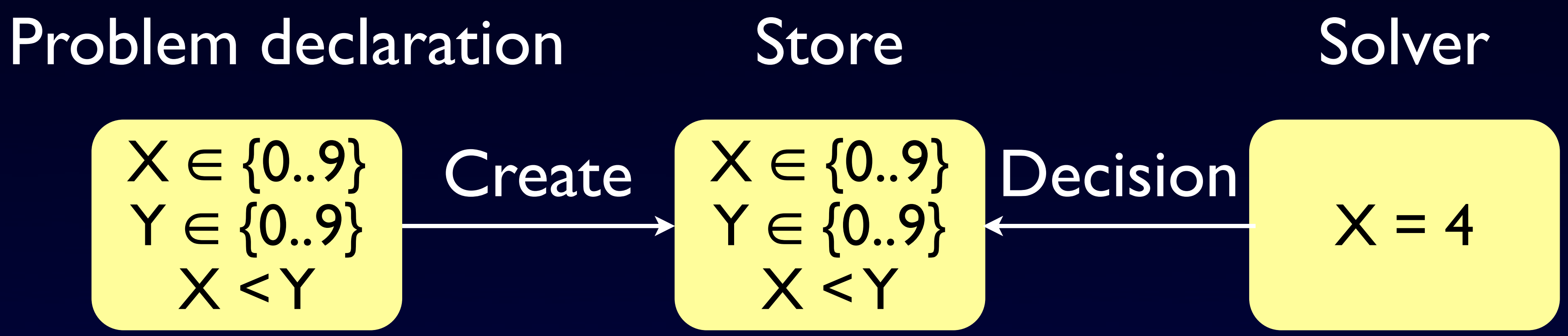
Problem declaration | Store | Solver

$X \in \{0..9\}$
$Y \in \{0..9\}$
$X < Y$

# Constraint Programming (CP)

Problem declaration Store Solver

# Constraint Programming (CP)



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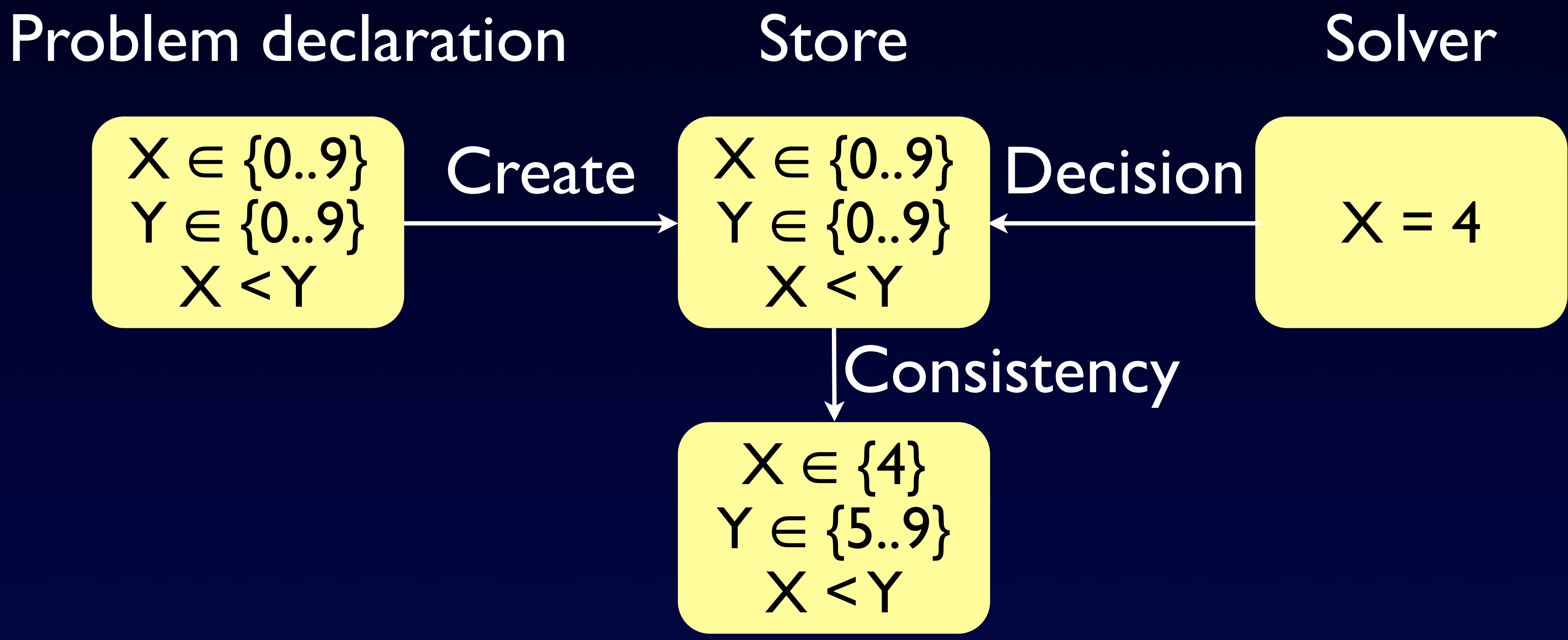

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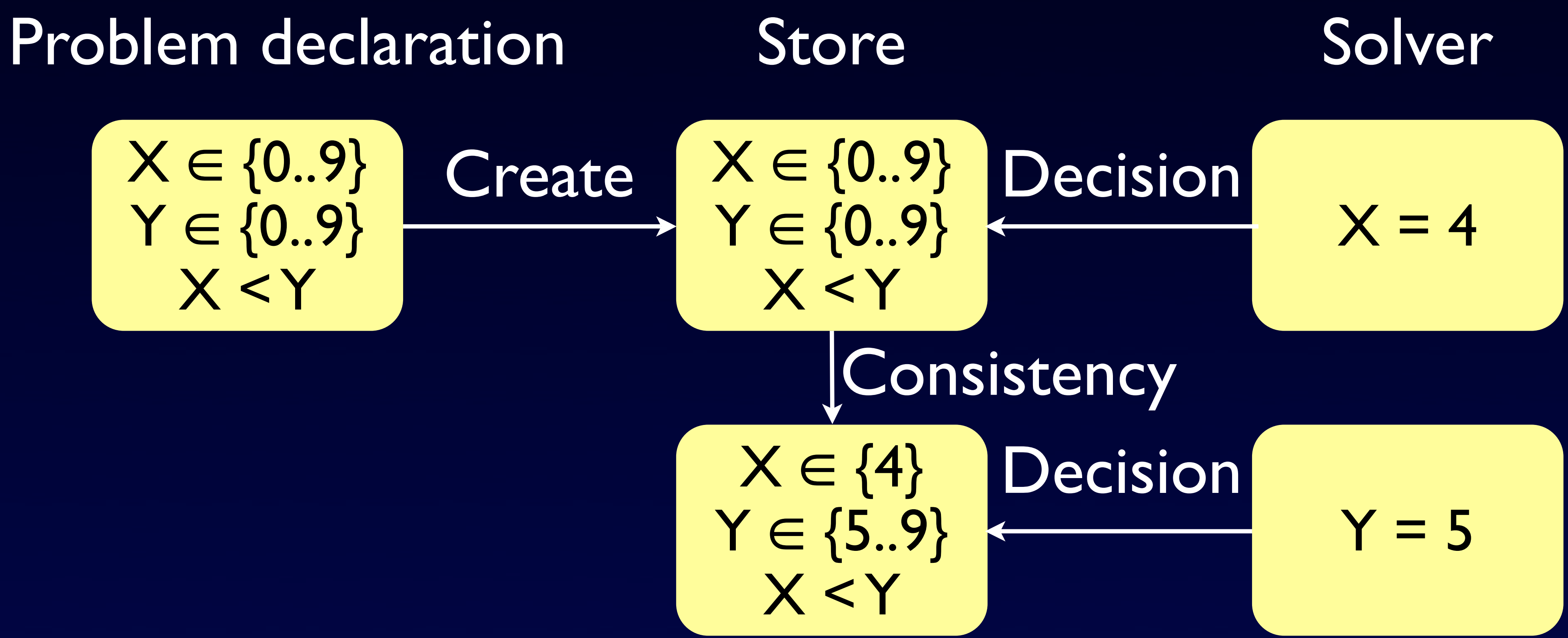

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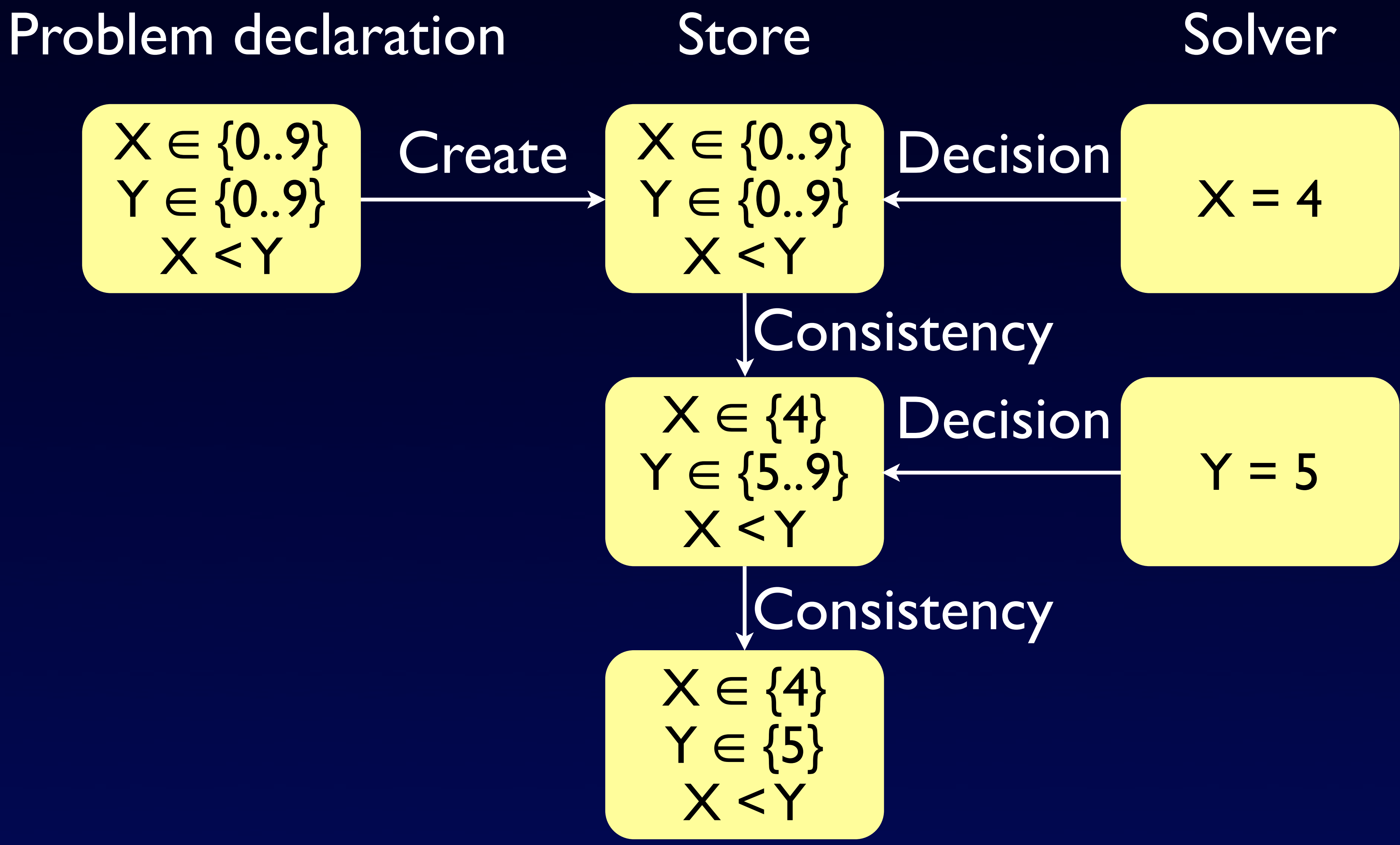

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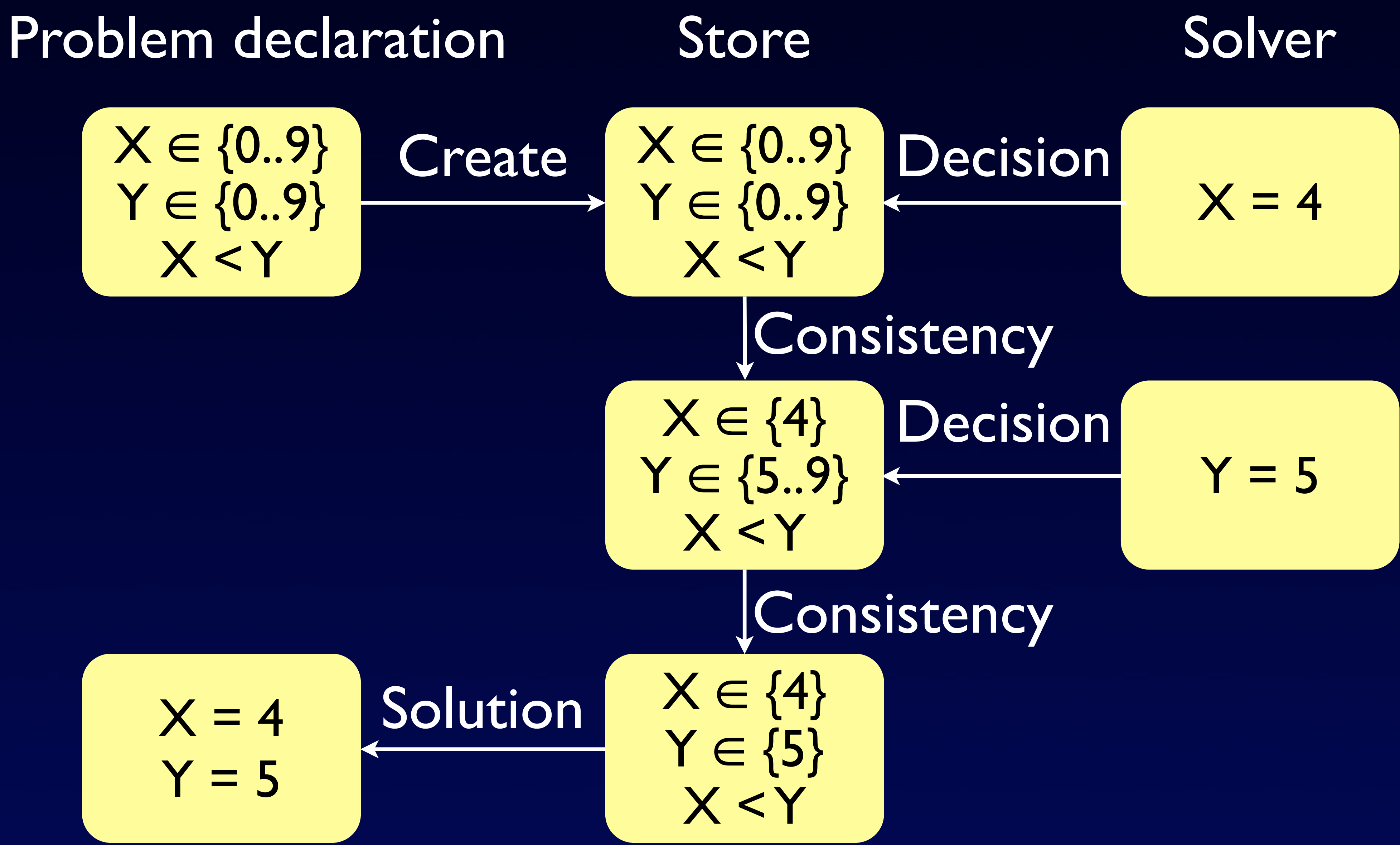
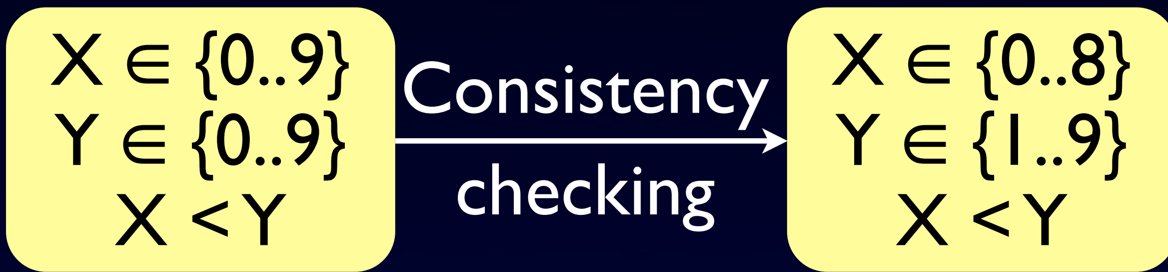


# Depth First Search in CP

$X \in \{0..9\}$
$Y \in \{0..9\}$
$X < Y$

# Depth First Search in CP



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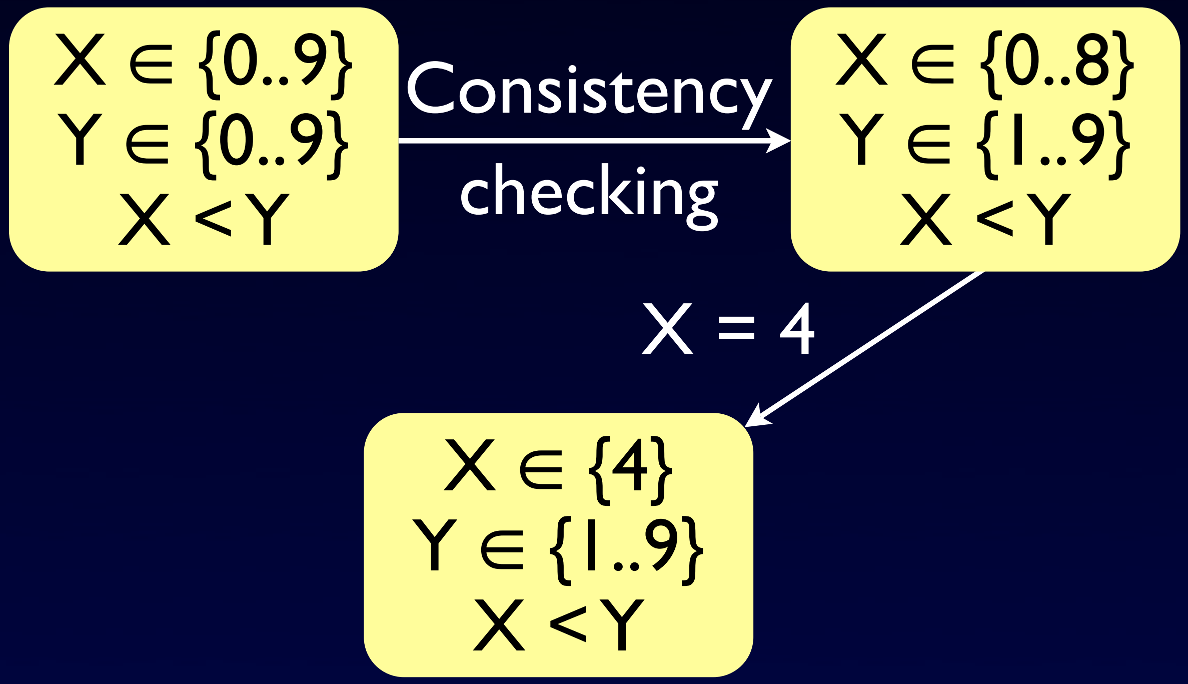

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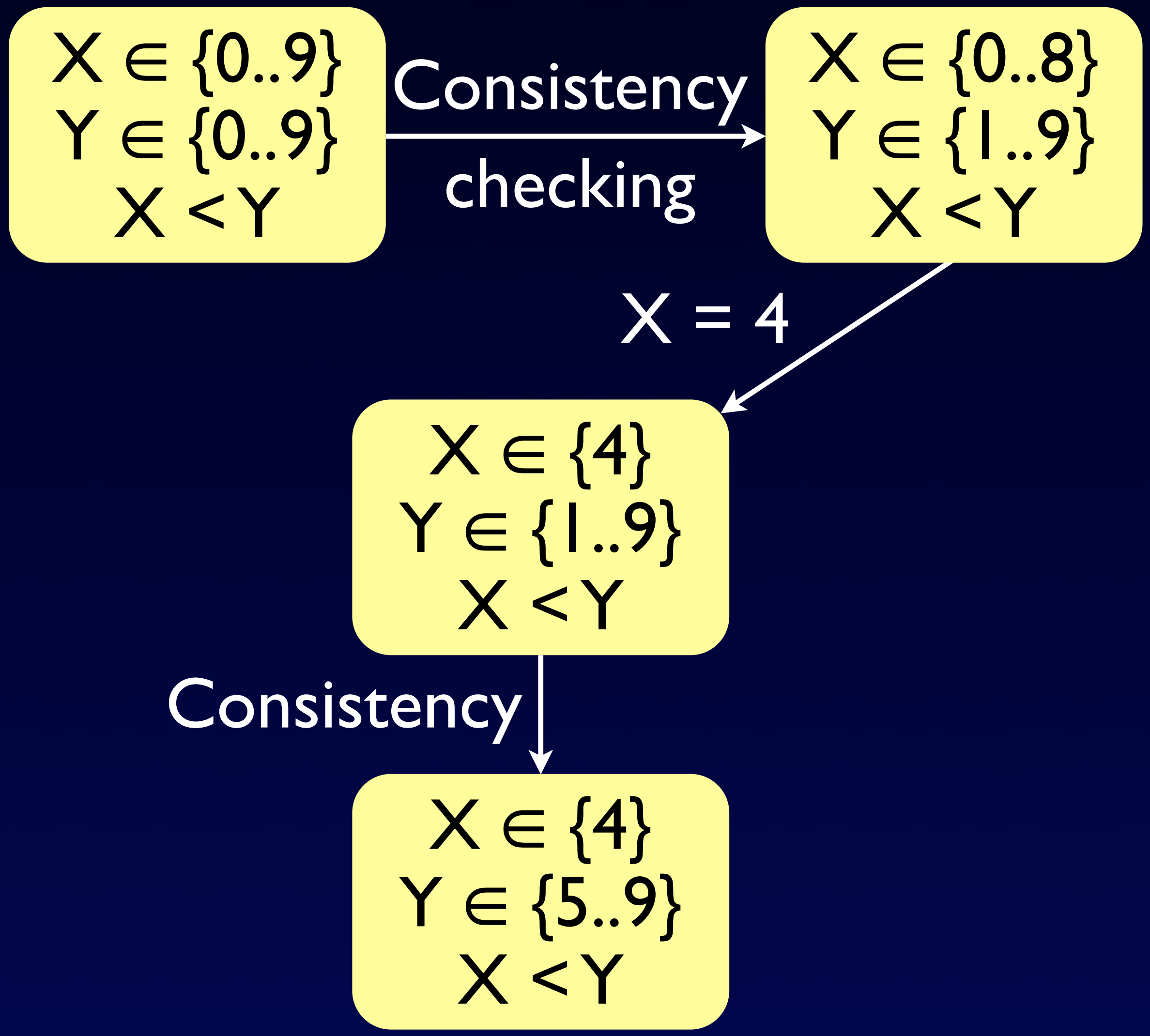

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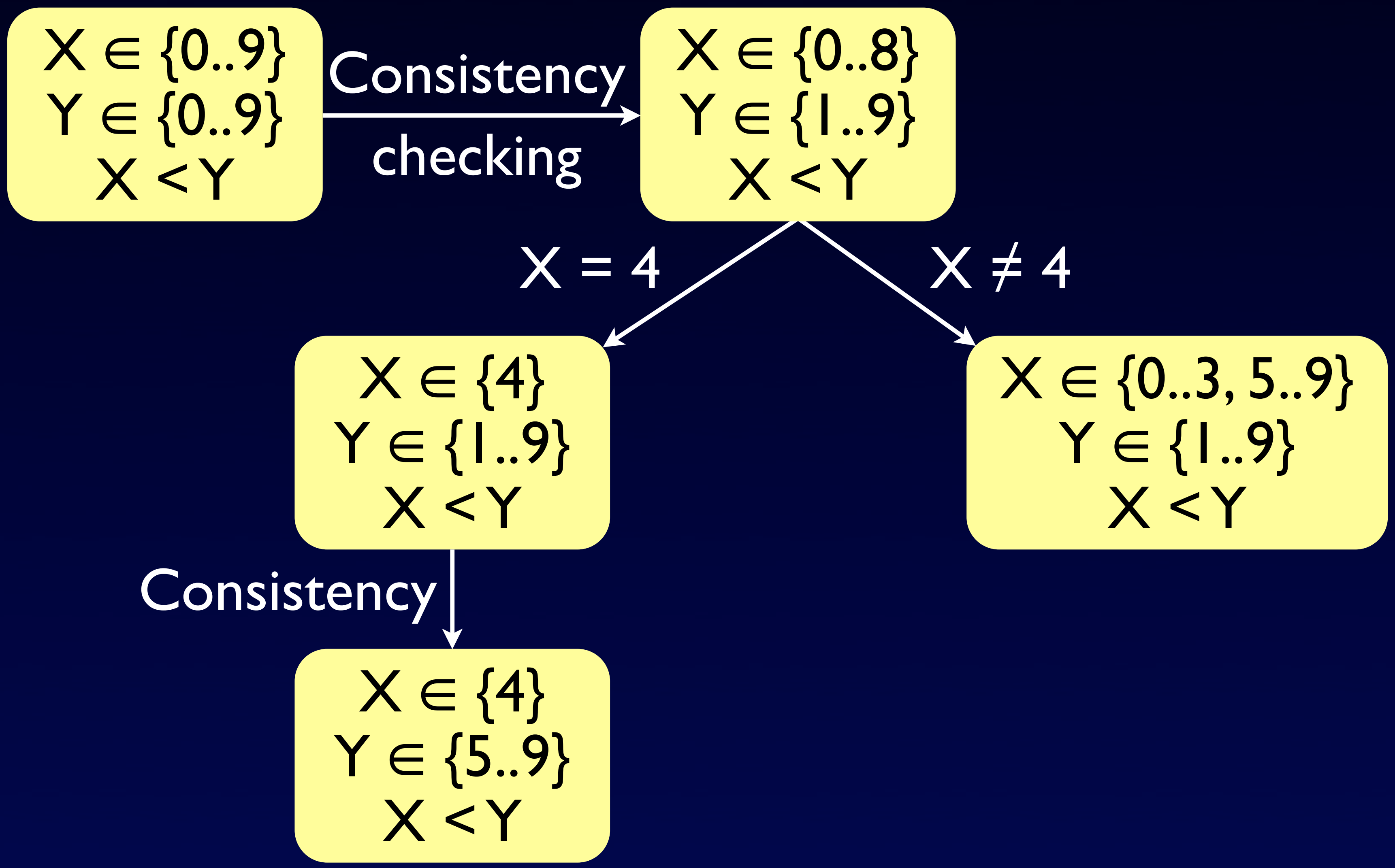

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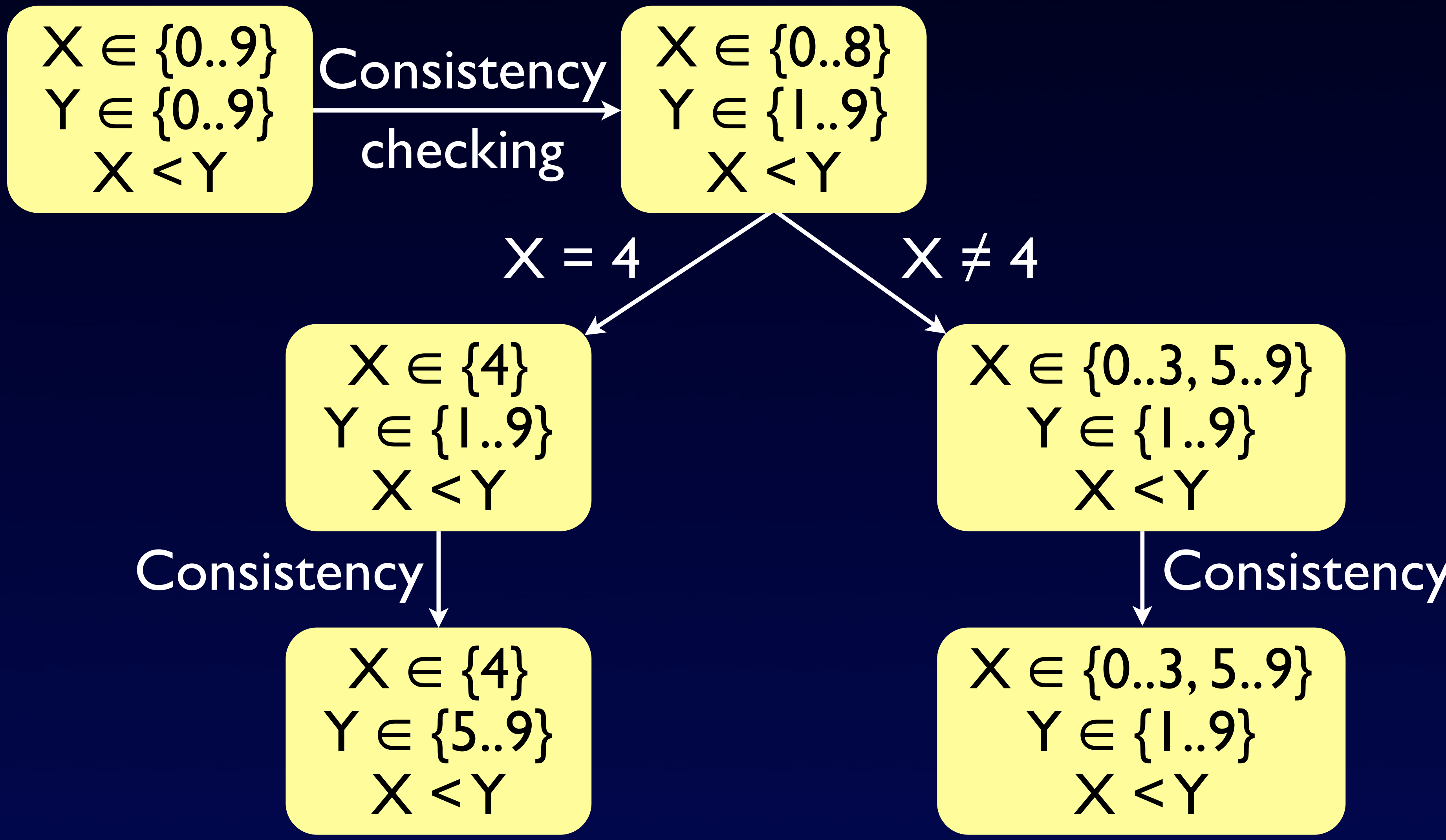

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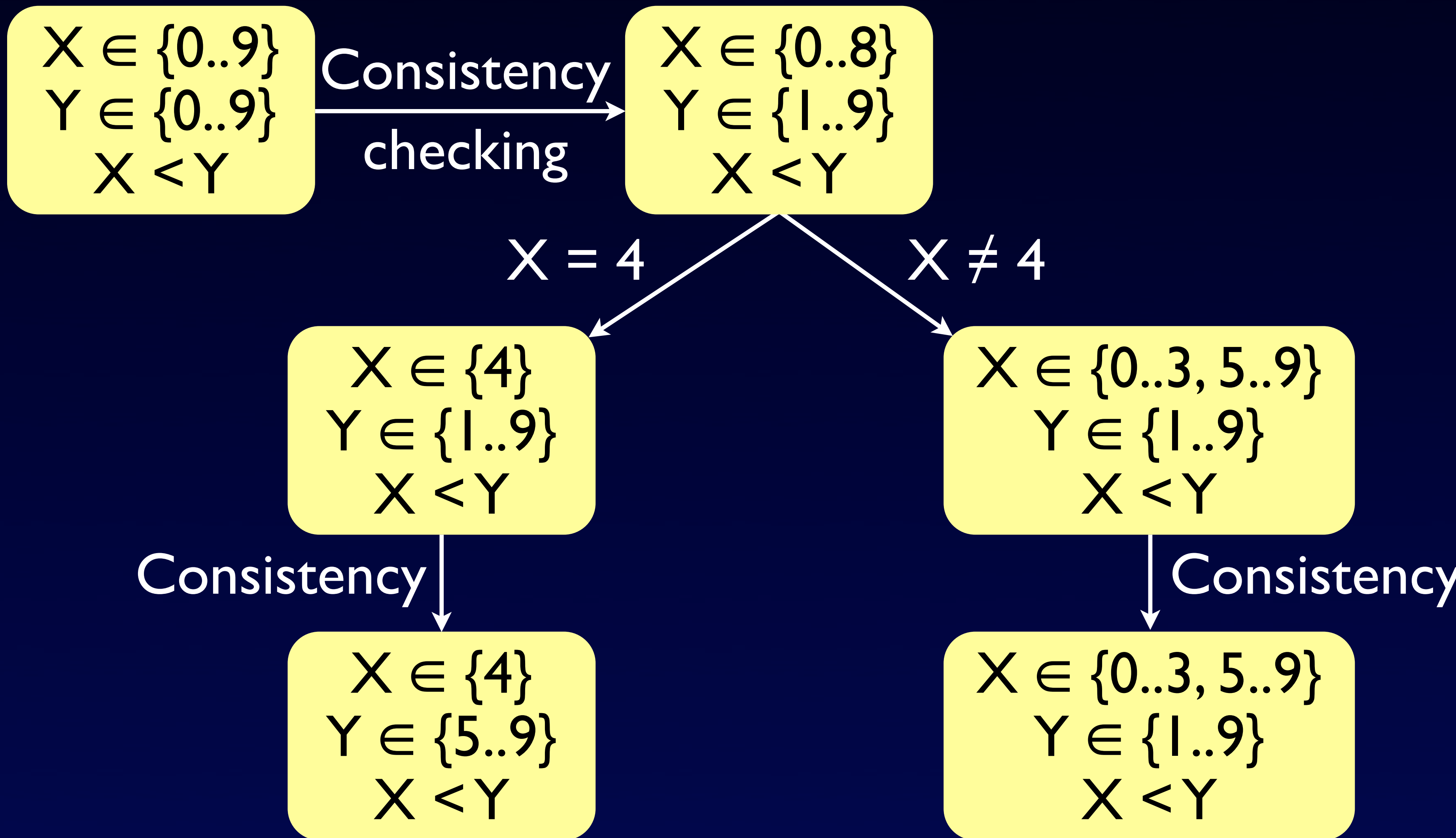



*The search tree changes shape during the search*

# Models of Communication

| | Local machine | Remote machine |
|---|---|---|
| State-copying | Variables<br>Domains<br>Constraints | Variables<br>Domains<br>Constraints |
| State-recomputation | Variables<br>Domains<br>Constraints | Variables<br>Domains<br>Constraints |

# Models of Communication

| | Local machine | | Remote machine |
|---|---|---|---|
| State-copying | Variables<br>Domains<br>Constraints | Variables<br>Domains<br>Constraints<br>→ | Variables<br>Domains<br>Constraints |
| State-recomputation | Variables<br>Domains<br>Constraints | | Variables<br>Domains<br>Constraints |

# Models of Communication

| | Local machine | | Remote machine |
|---|---|---|---|
| State-copying | Variables<br>Domains<br>Constraints | → Variables<br>Domains<br>Constraints | Variables<br>Domains<br>Constraints<br>Replace references |
| State-recomputation | Variables<br>Domains<br>Constraints | | Variables<br>Domains<br>Constraints |

# Models of Communication

Local machine — Remote machine

**State-copying**

Variables / Domains / Constraints → (Variables, Domains, Constraints) → Variables / Domains / Constraints

Replace references

**State-recomputation**

Variables / Domains / Constraints → (Assignments performed) → Variables / Domains / Constraints

# Models of Communication

Local machine | Remote machine

**State-copying**

Variables, Domains, Constraints → (Variables, Domains, Constraints) → Variables, Domains, Constraints

Replace references

**State-recomputation**

Variables, Domains, Constraints → (Assignments performed) → Variables, Domains, Constraints

Perform assignments, compute consistency

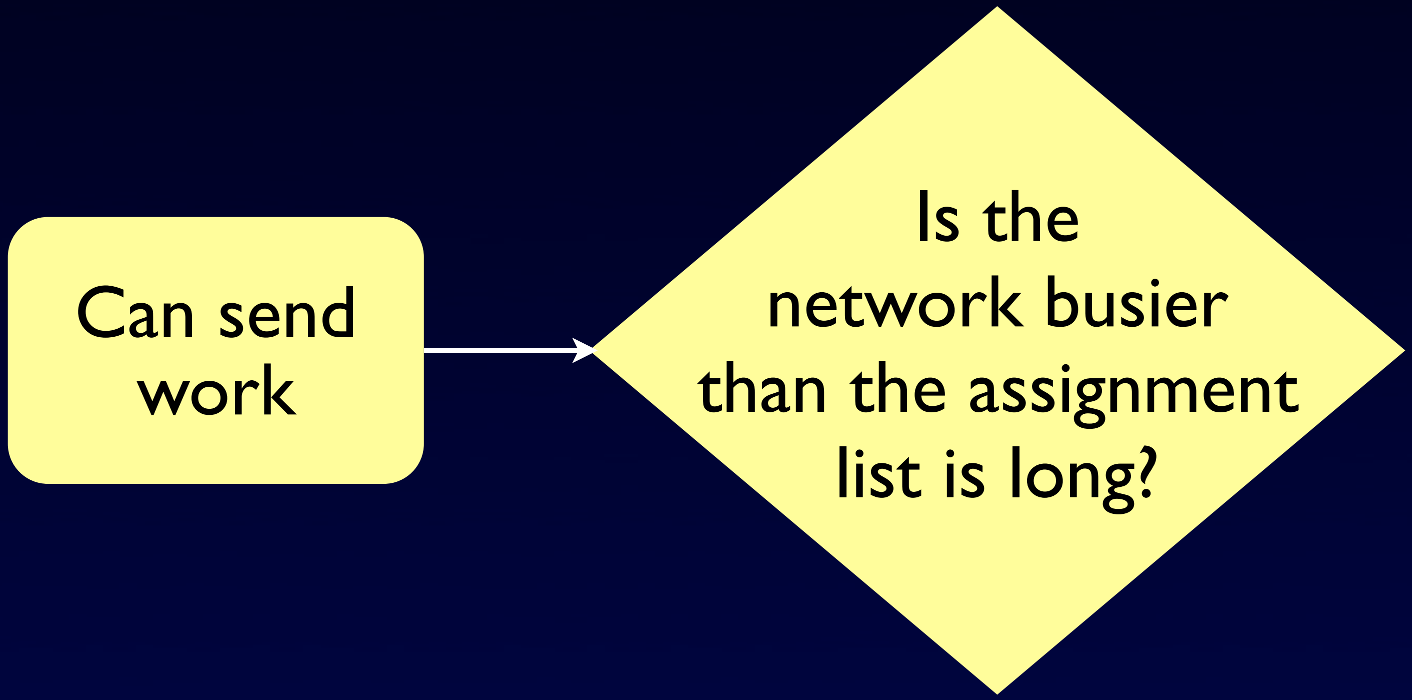
# Problem

- Copying sometimes too slow
- Recomputation not always faster

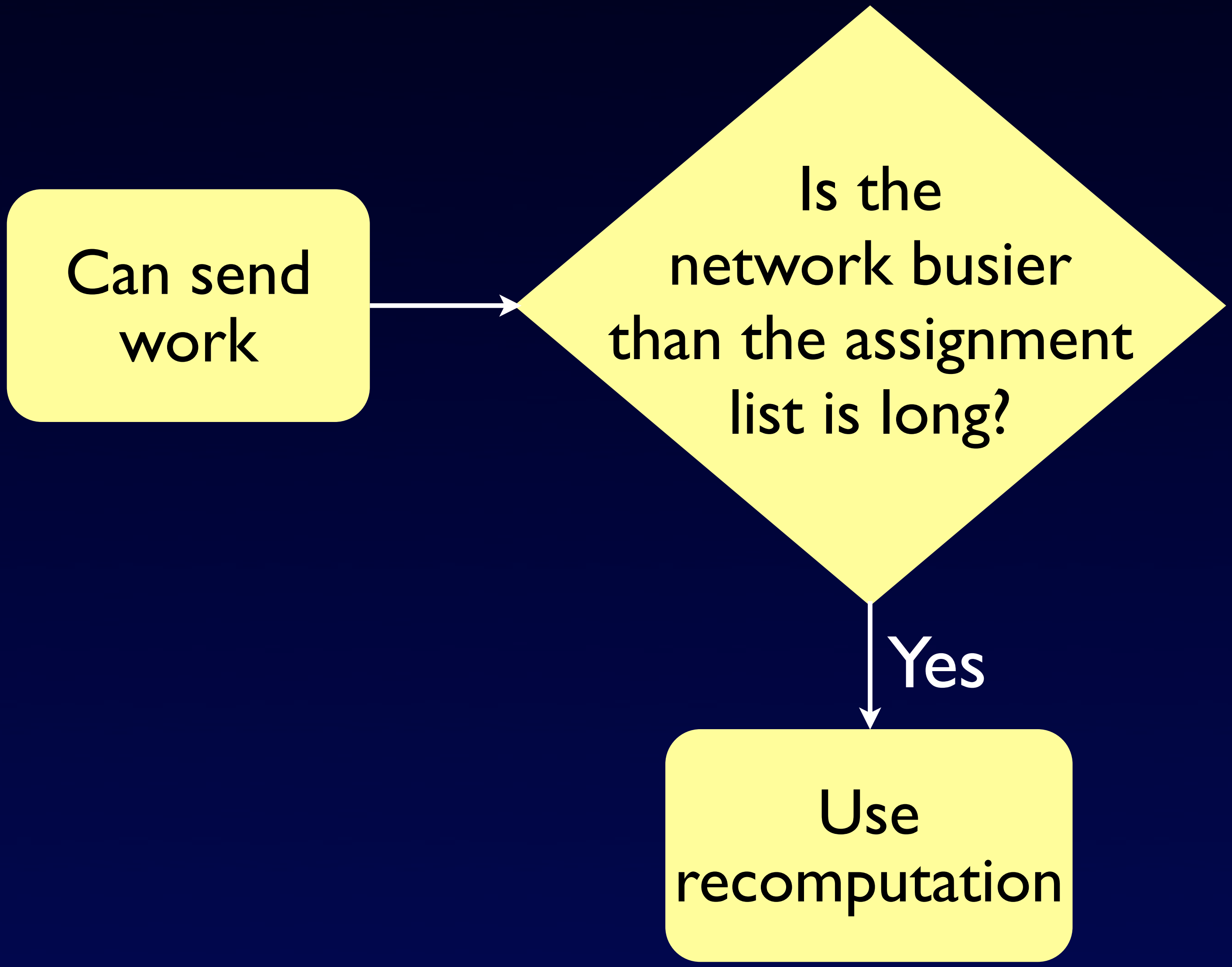
# Our Solution: *Dual Com*

Can send work

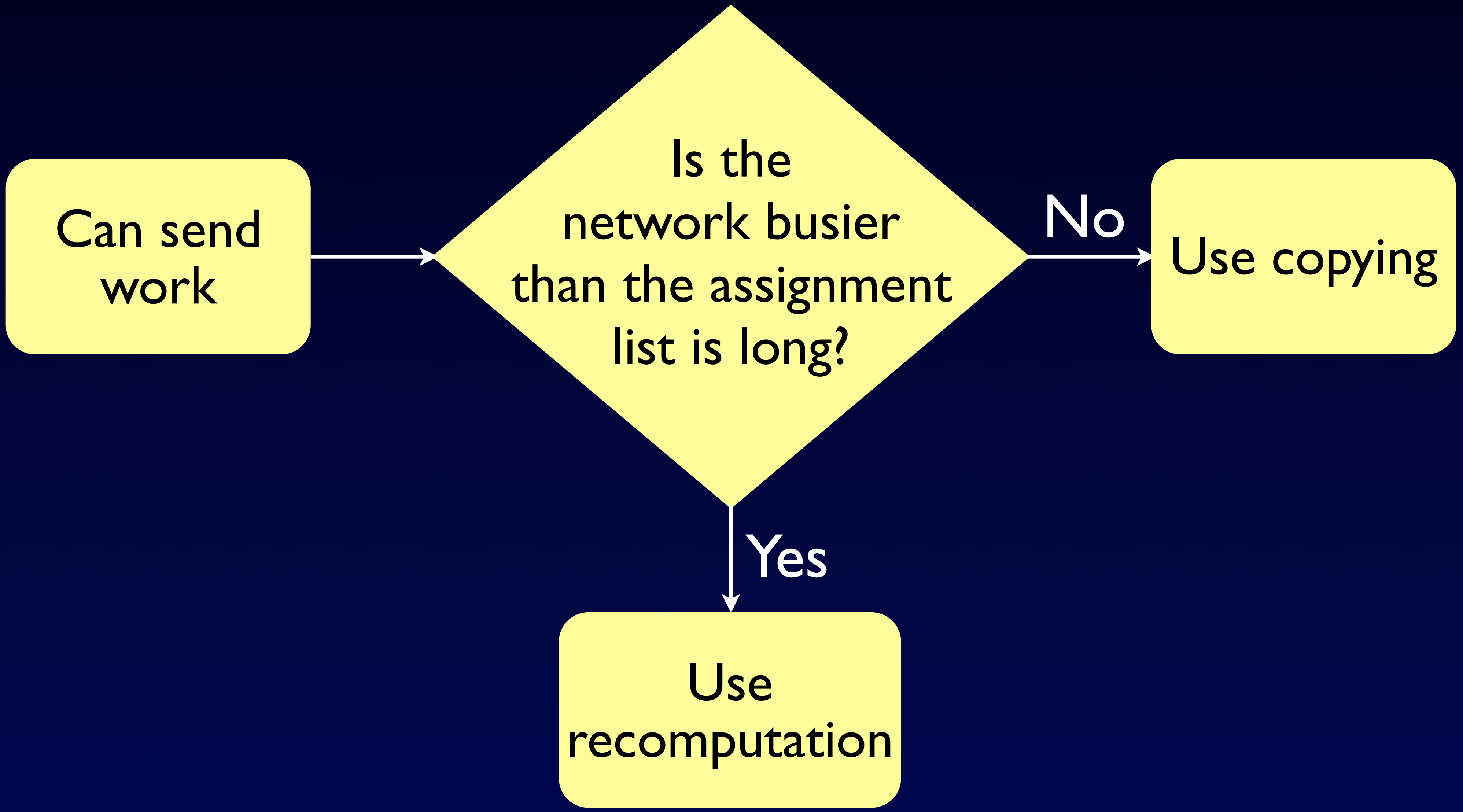
# Our Solution: *Dual Com*



# Our Solution: *Dual Com*



# Our Solution: *Dual Com*

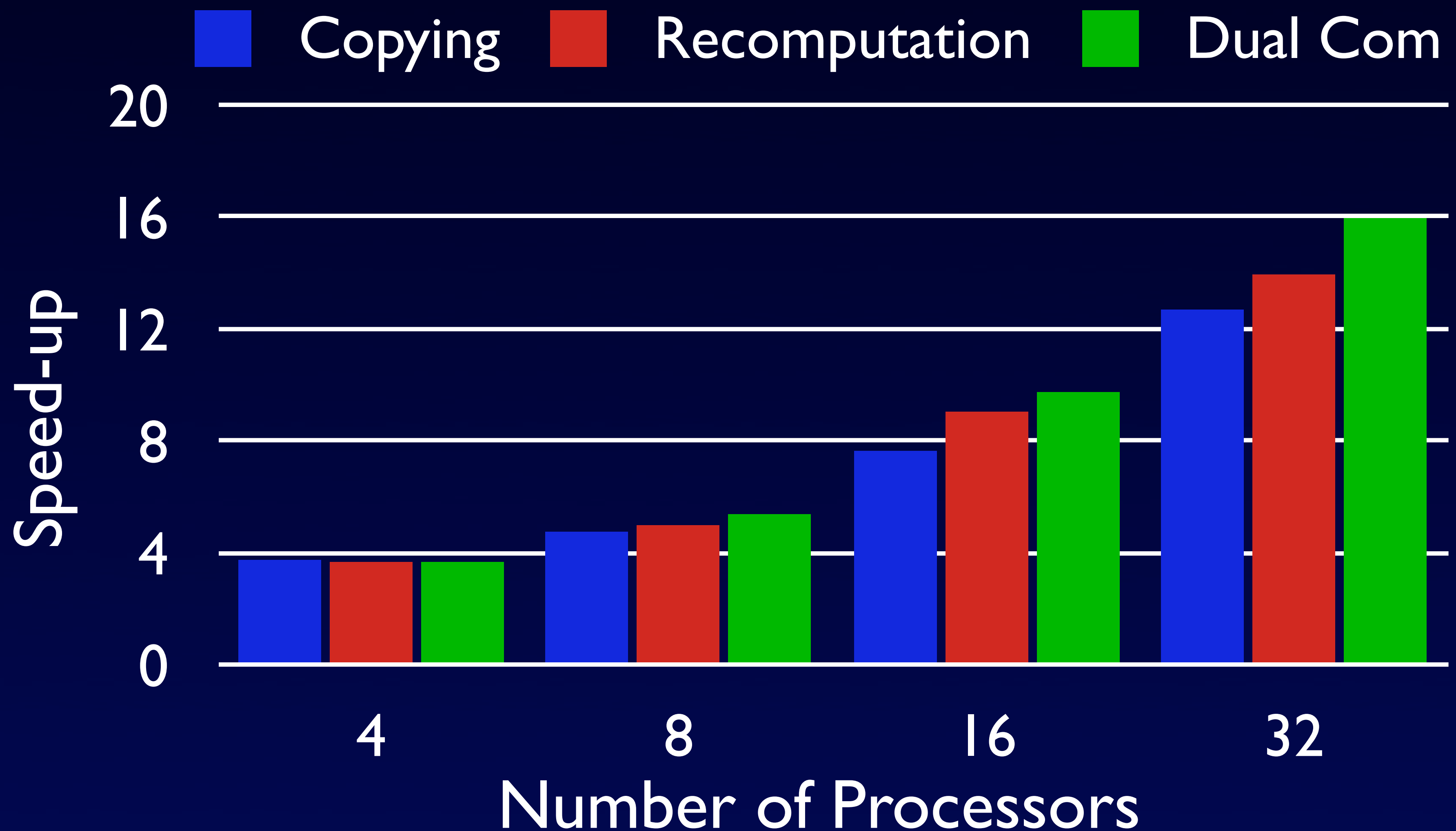


# Experiment Setup

- Benchmark Problems: Golomb, n-Queens
- Cluster of AMD Opteron 2.2 GHz CPUs
- 1 MB cache per processor
- Gigabit Ethernet network
- CentOS Linux 4.4

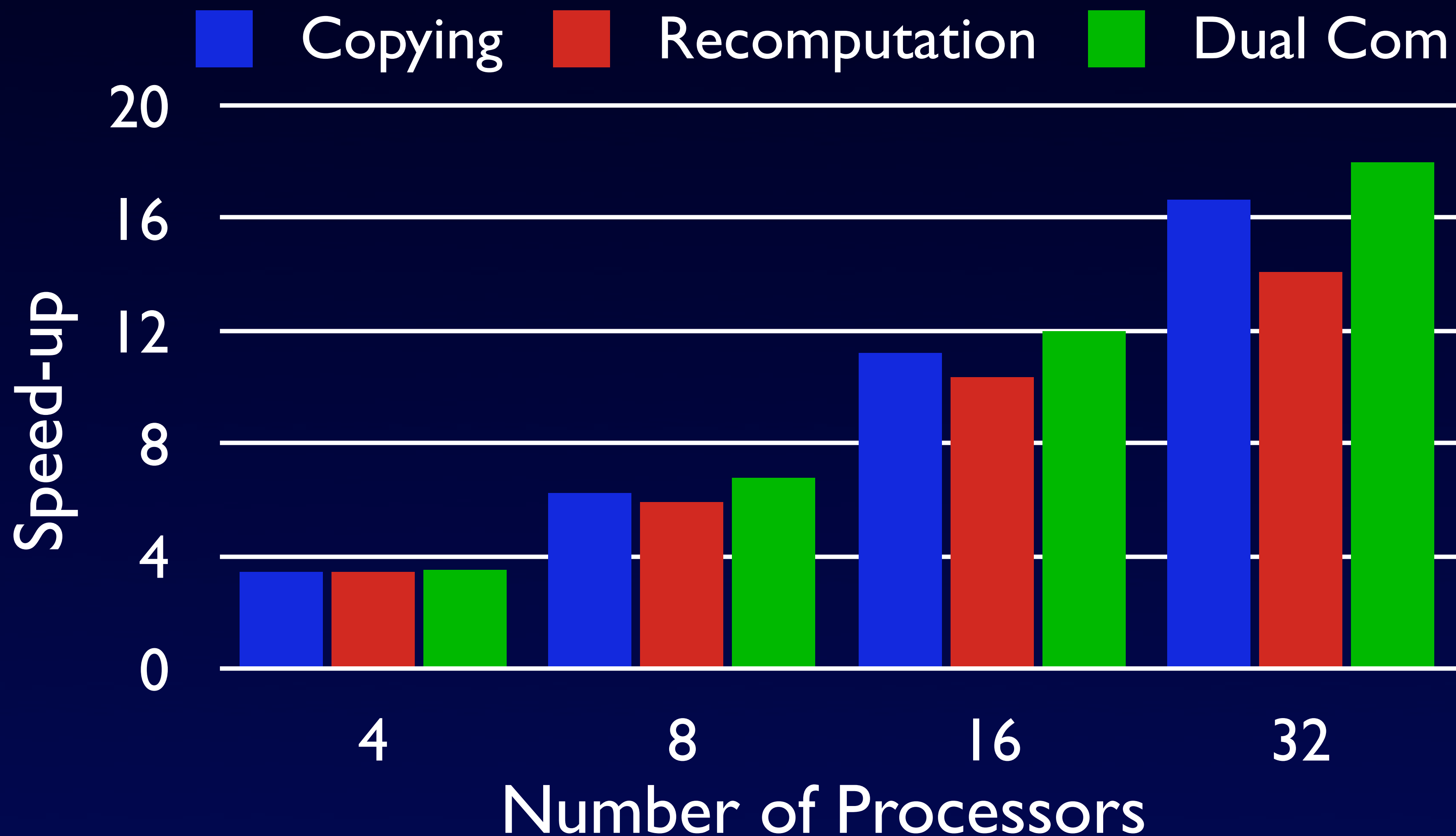
# Experiment: Optimal Golomb Ruler

*Proving* the optimality with n = 12



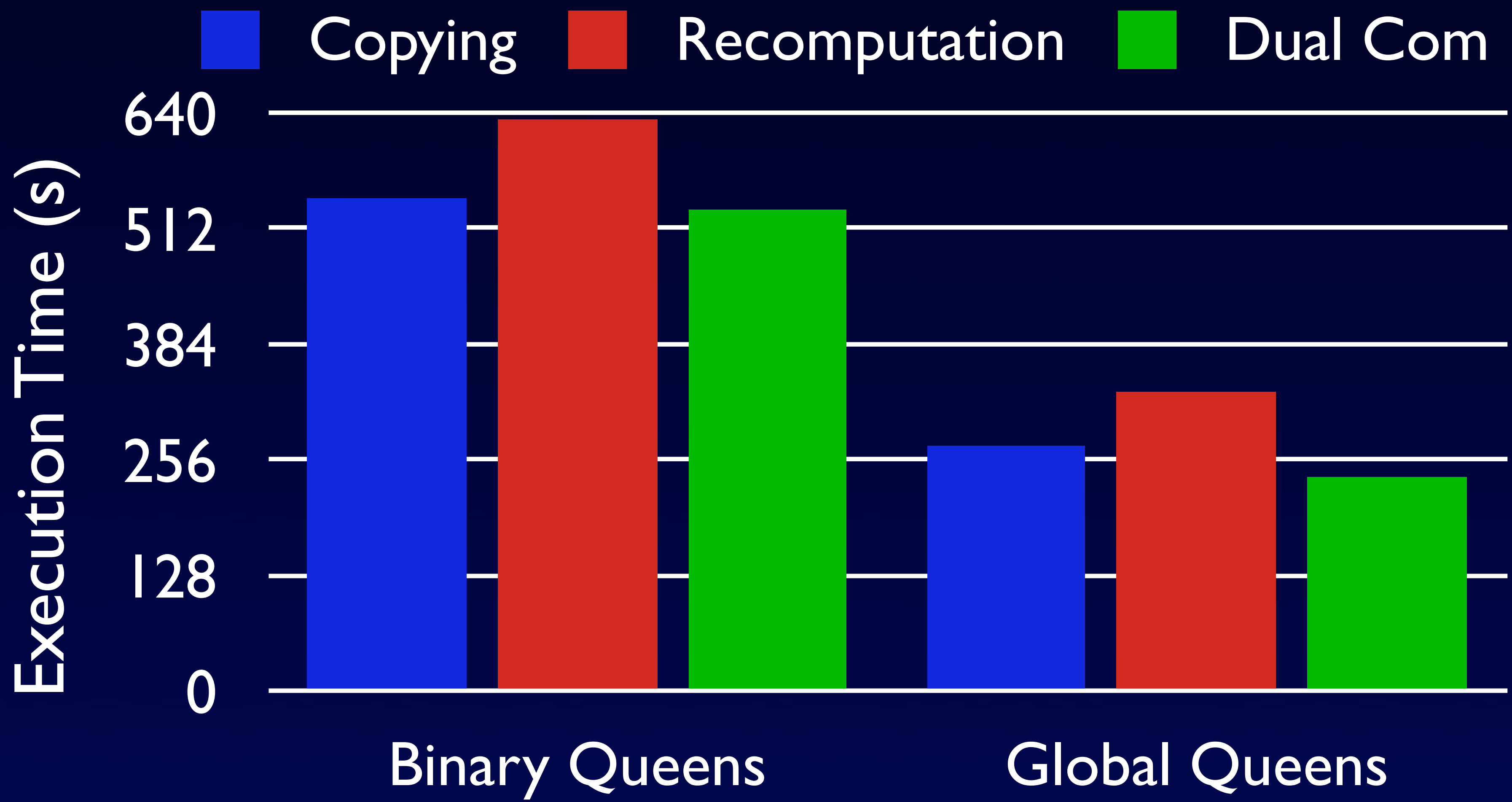
# Experiment: n-Queens

Finding *all* solutions with n = 15



# Benefit of Global Constraints

X ≠ Y ≠ Z → alldifferent({X, Y, Z})




Results for 32 Processors

# Conclusions

- Dual Com faster than copying or recomputation
- Global constraints doubles the performance
- Global constraints increases benfit of Dual Com