

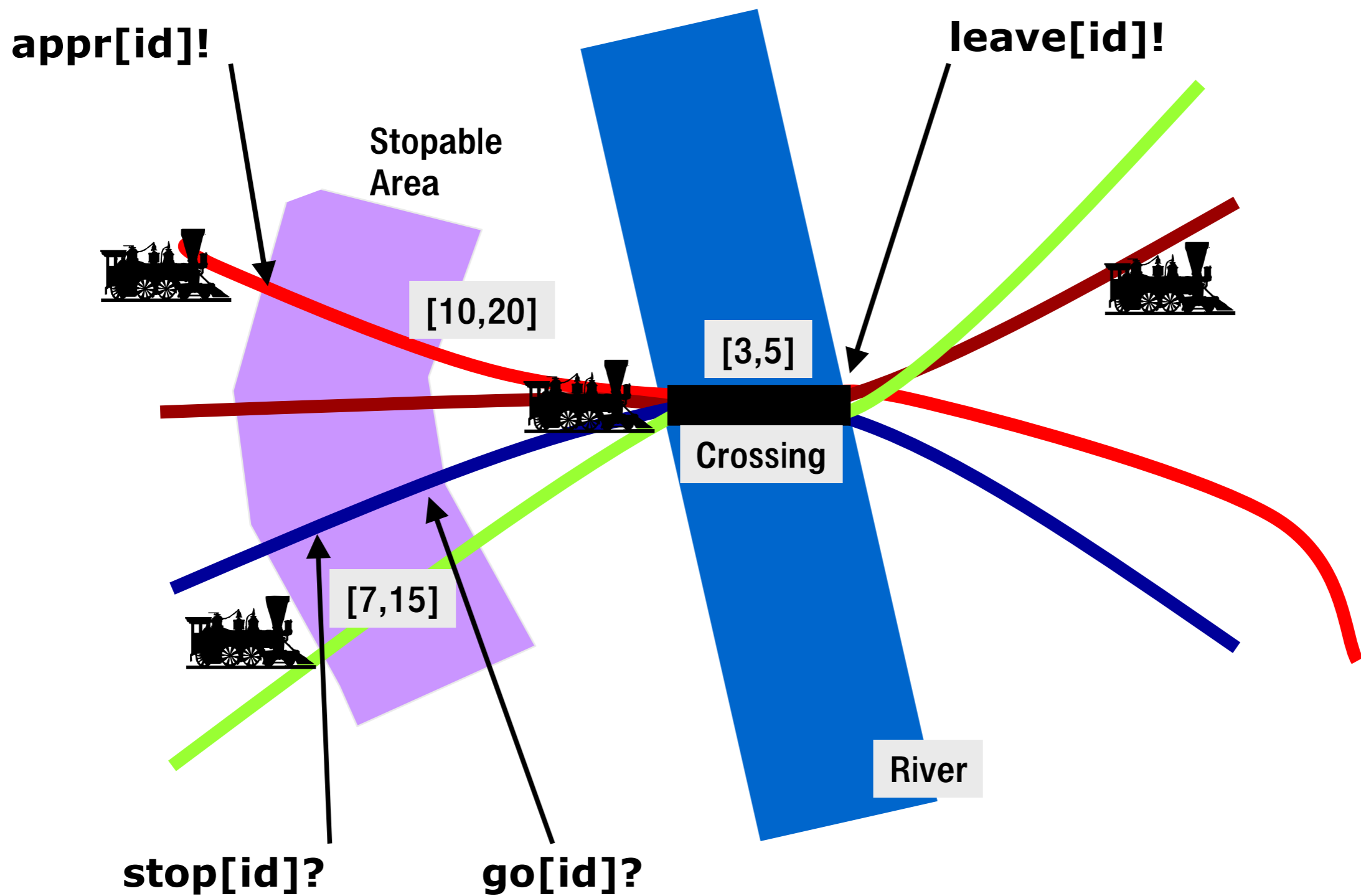


Slicing for UPPAAL

Claus Thrane, Uffe Sørensen and Kim G. Larsen

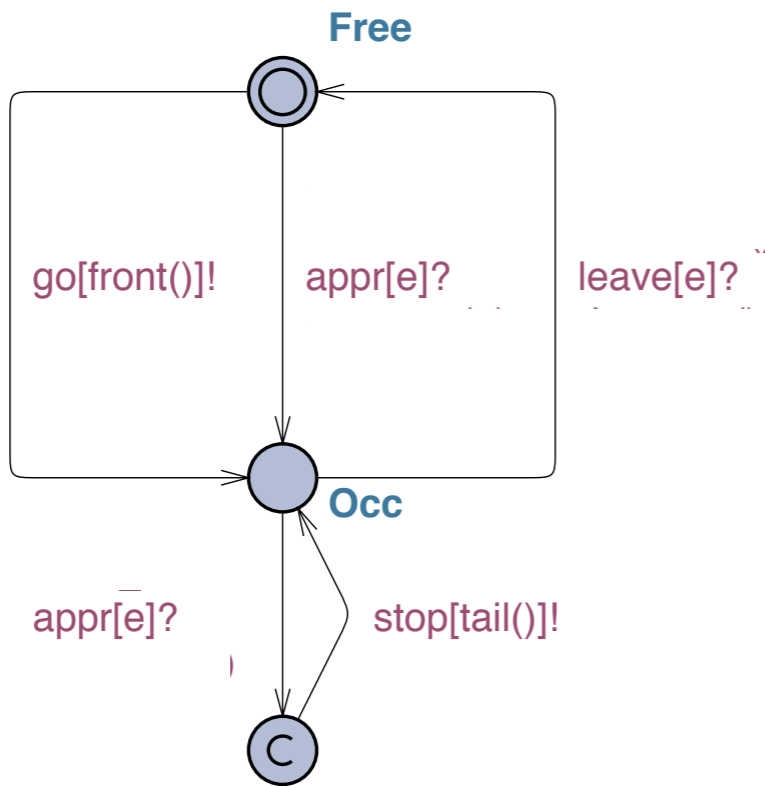
NWPT'08

Modeling Real-Time Systems

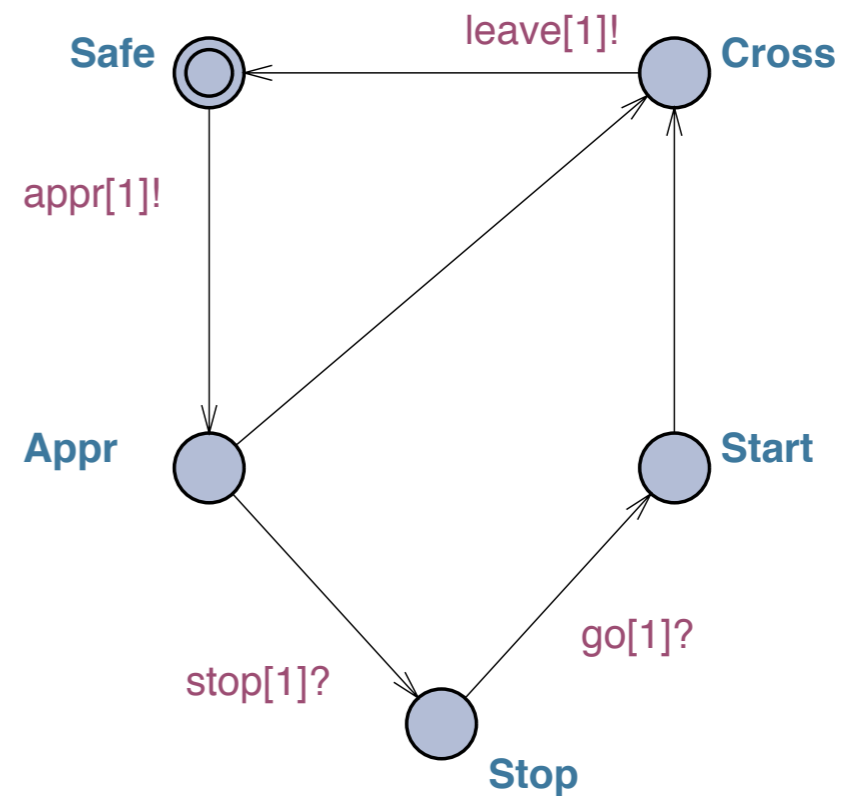


Communicating FSA

Gate



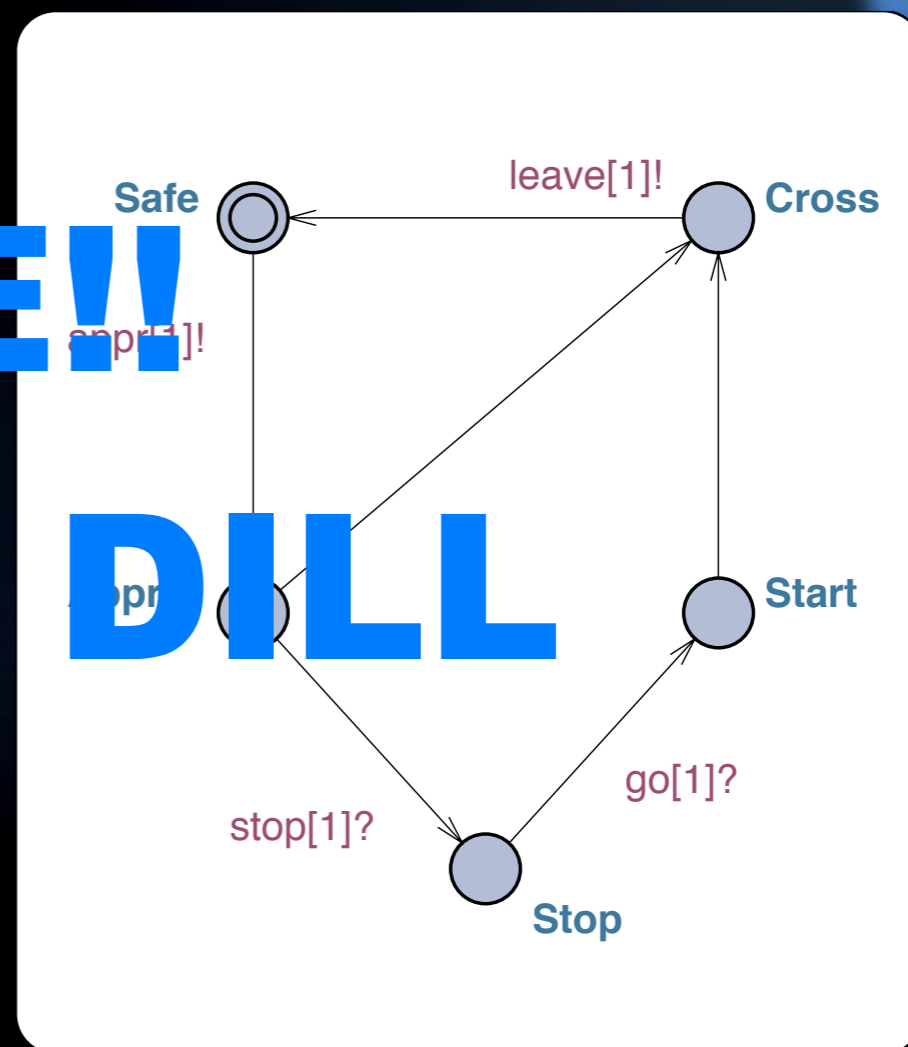
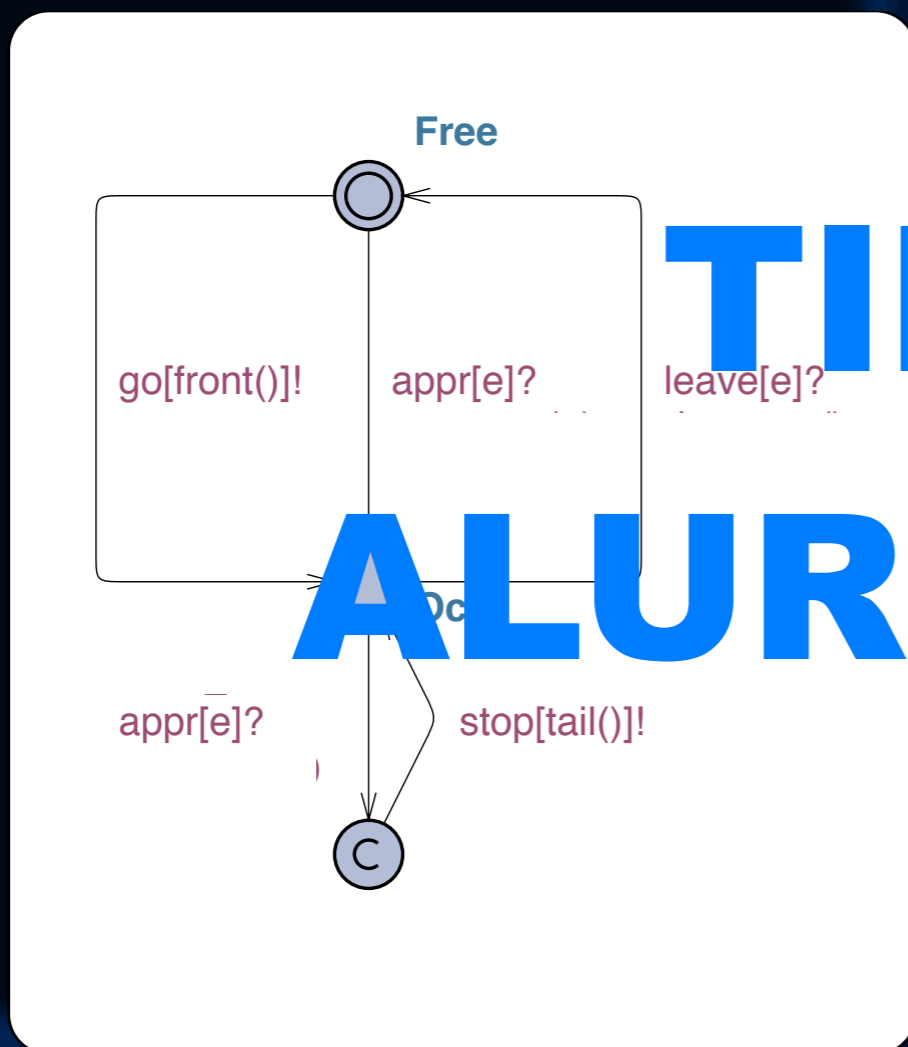
Train



Communicating FSA

Gate

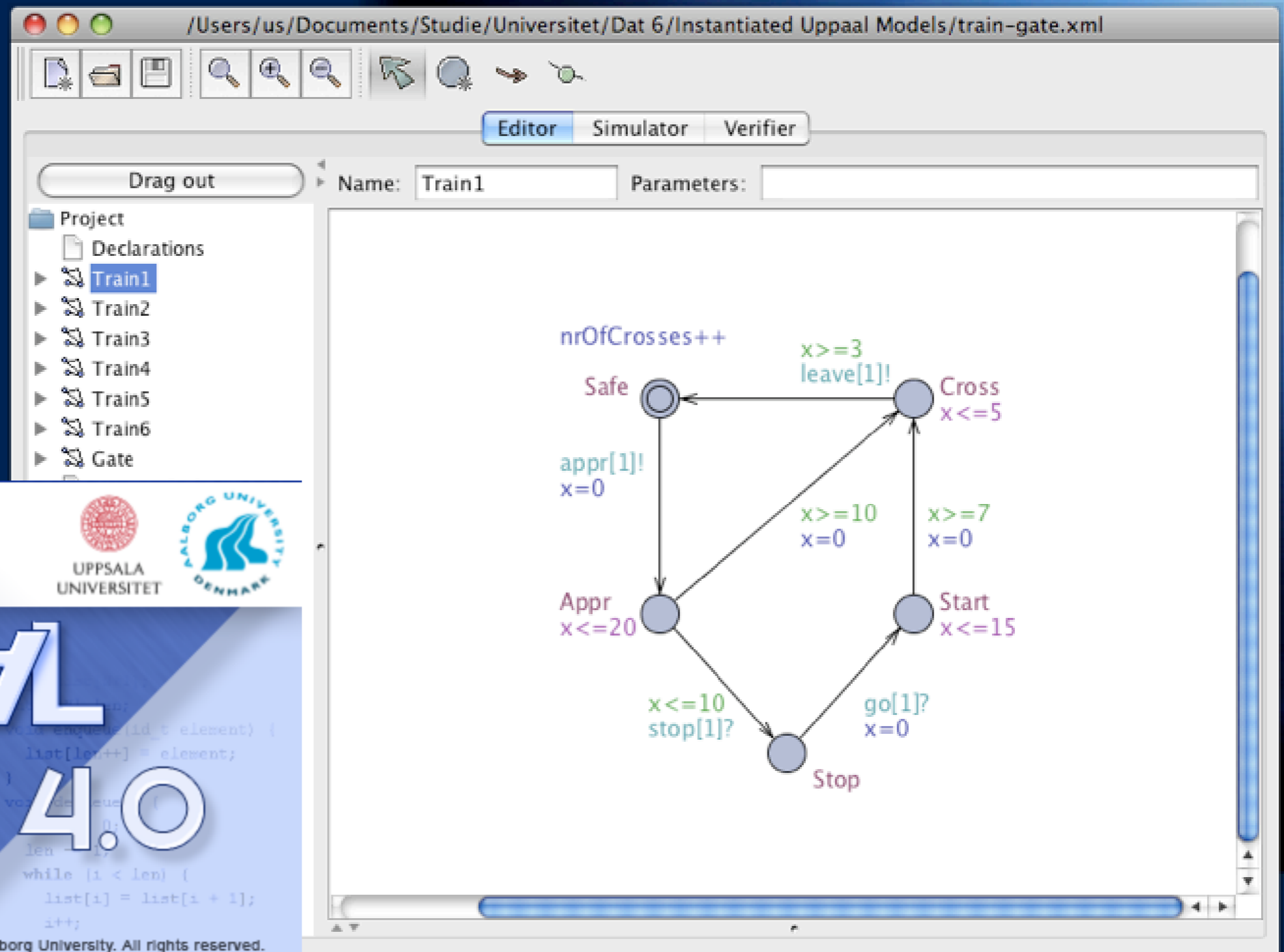
Train



TIME!!

&

UPPAAL



UPPSALA UNIVERSITET

AALBORG UNIVERSITY DENMARK

UPPAAL 4.0

```
void enqueue(id t element) {
  list[len++] = element;
}
void dequeue() {
  len--;
}
while (i < len) {
  list[i] = list[i + 1];
  i++;
}
list[i] = 0;
```

Start

Appr

Safe

Stop

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More Information at <http://www.uppaal.com>

Imperative code

```
clock x1, x2, .... ,xn;
```

```
int[0,5] i1, i2, .... ,in;
```

```
const int delay = 5;
```

```
int a[4] = {1,8,7,42};
```

```
bool b;
```

```
struct{int a; int b;}a = {9, 42};
```

```
typedef int[1,7] id_t;
```

```
if(...){...}
```

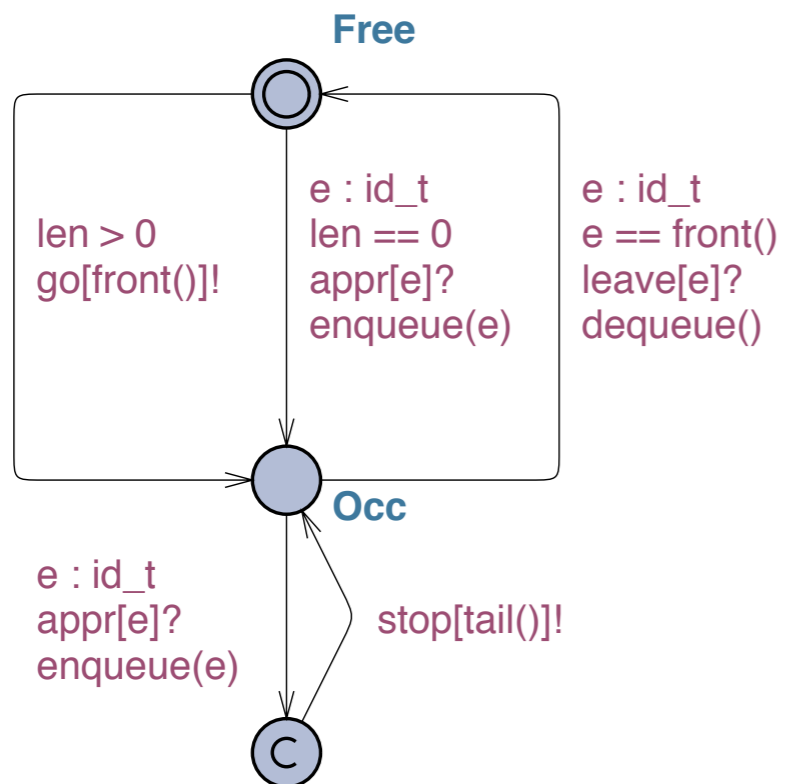
```
while(...){...}
```

```
for(;;){...}
```

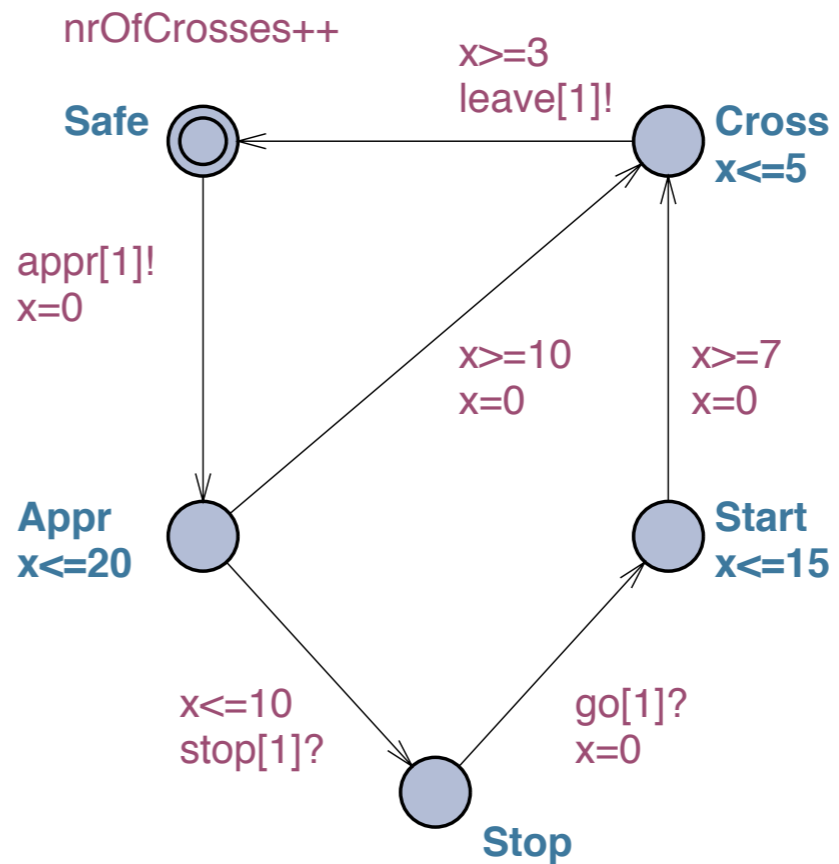
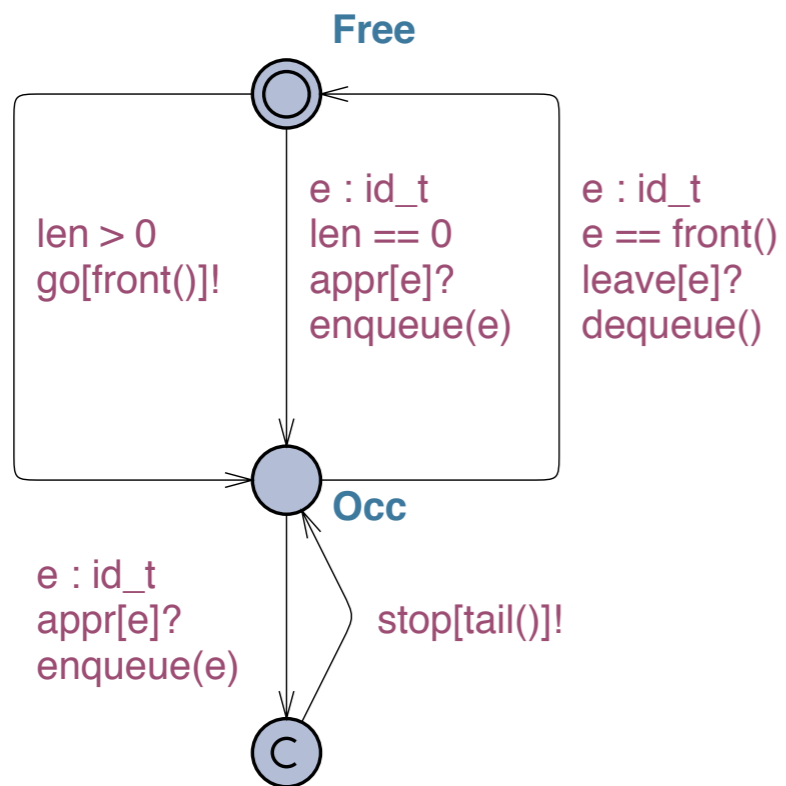
```
id_t foo(...)  
{  
    ...  
    return ..  
}
```

UPPAAL Model

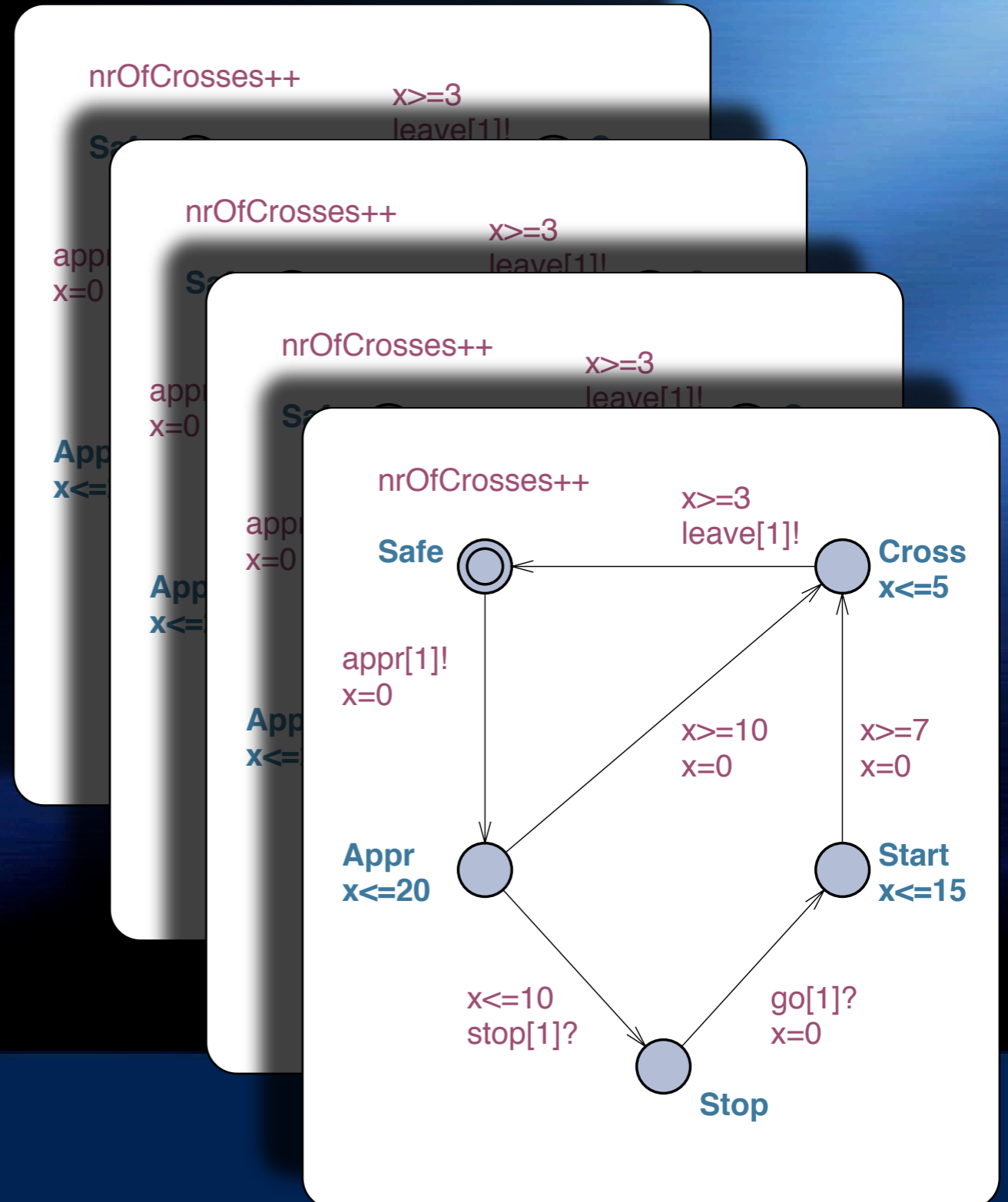
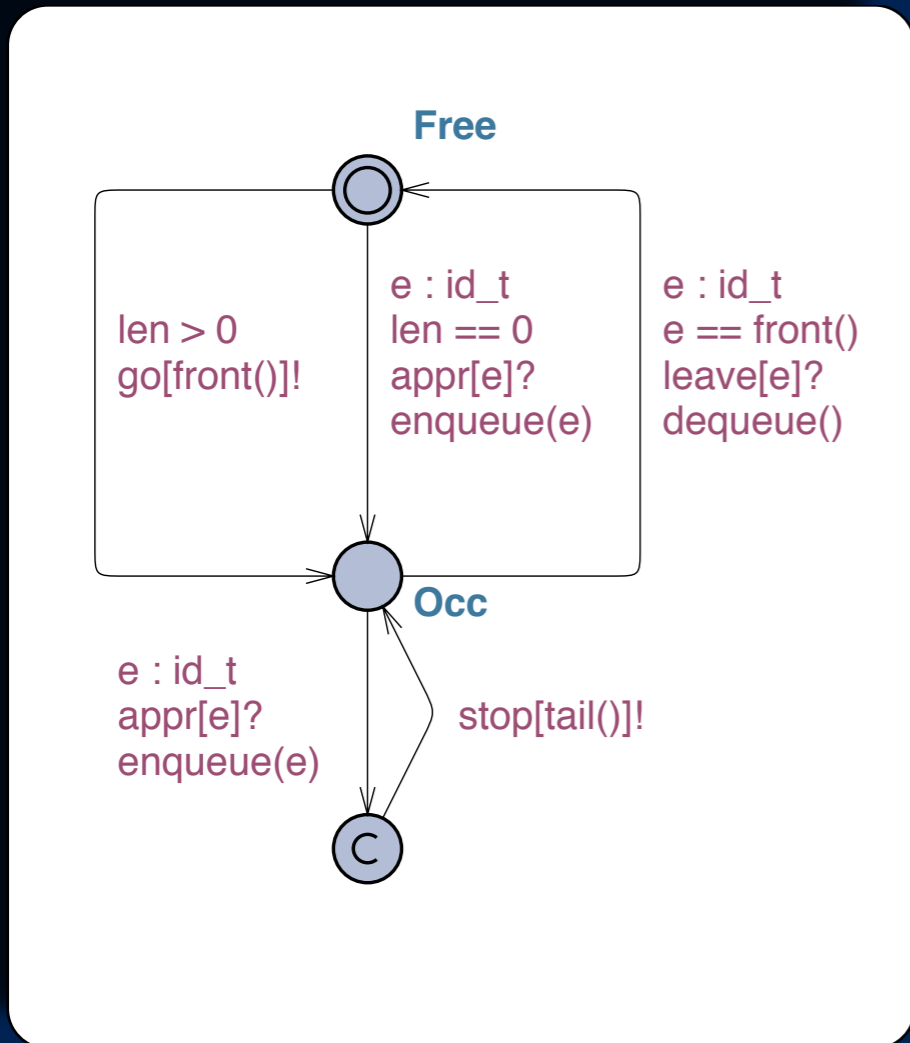
UPPAAL Model



UPPAAL Model



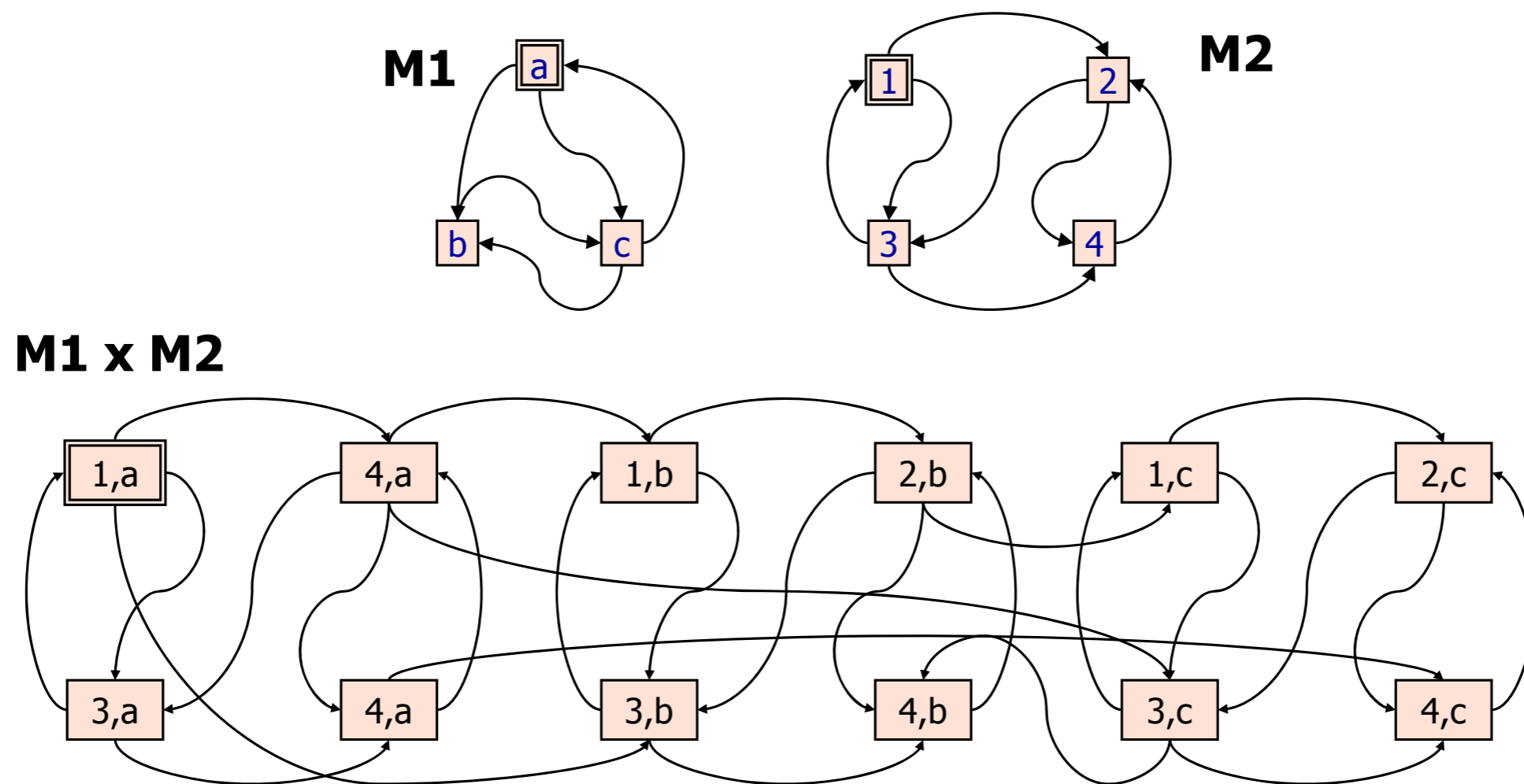
UPPAAL Model



Motivation

Model-checking Timed Automata is PSPACE-Complete

State-space explosion problem



We propose

- Static analysis, specifically slicing can be used on the “hybrid” modeling language of UPPAAL - to improve the tool’s performance.

Slicing

Weiser: *“a slice corresponds to the mental abstractions made by people while debugging programs”*

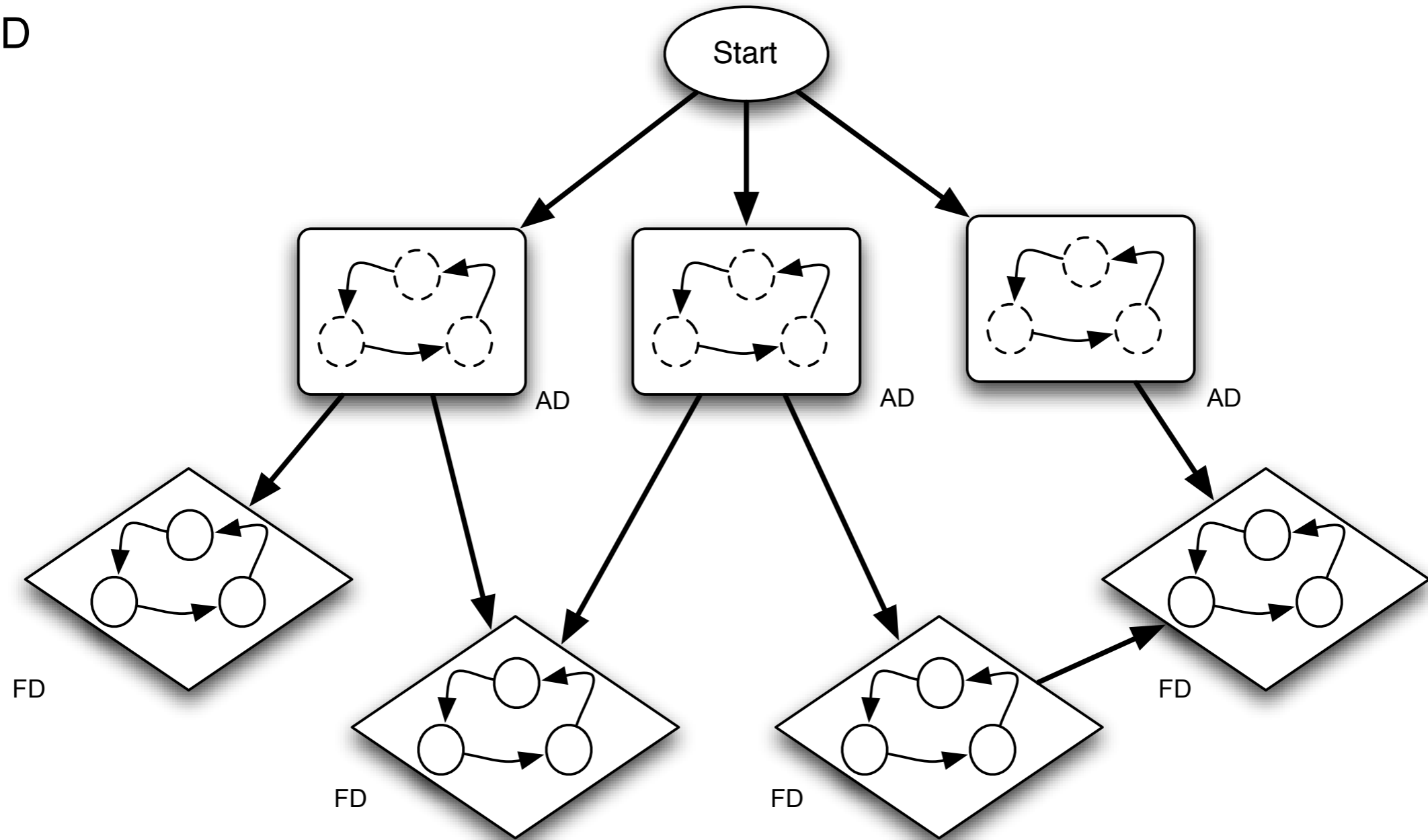
Traditionally used for removing irrelevant components during debugging and testing

- Slicing for TA w. simple data - Janowska and Janowski
- Used in SPIN and IF (KRONOS) to reduce the syntactic size of models prior to verification

System Dependency Graph

[S. Horwitz, T. Reps, and D. Binkley]

SD



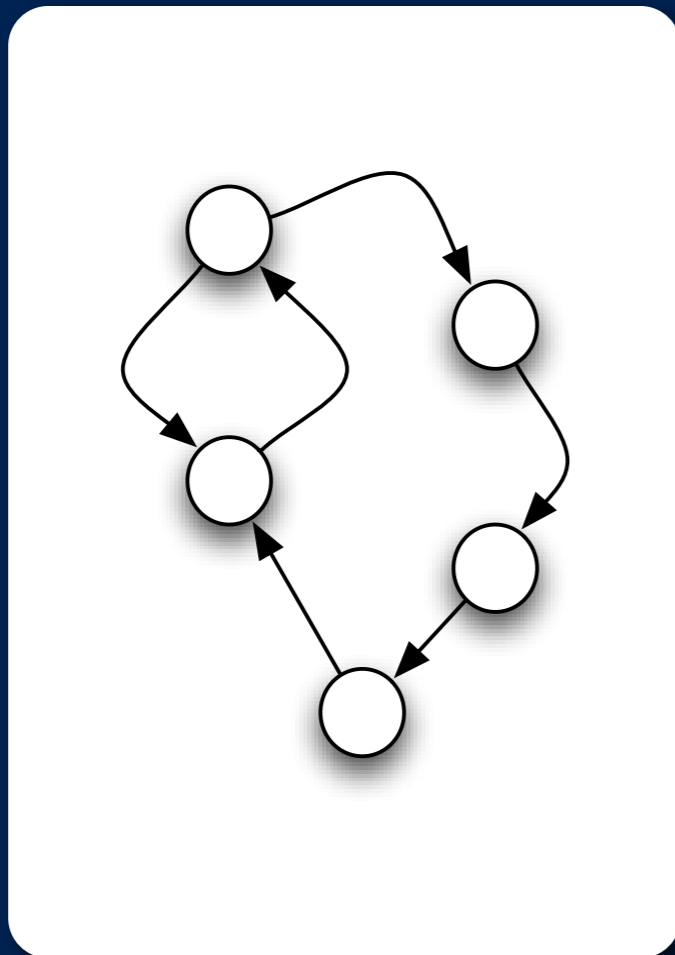
Dependencies

- Control Dependencies - Control Edges
 - Control Flow Graph
- Data Dependencies - Data Flow Edges
 - Reaching (or Use/Def chains)

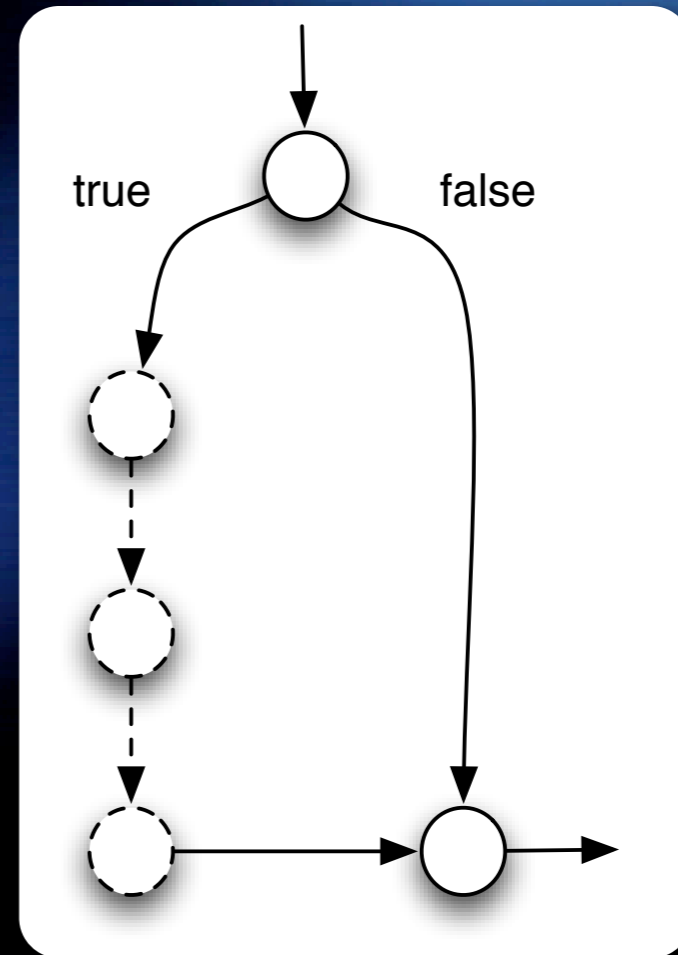
Control-Flow Graph

- Explicit and Implicit Control-Flow

FSA



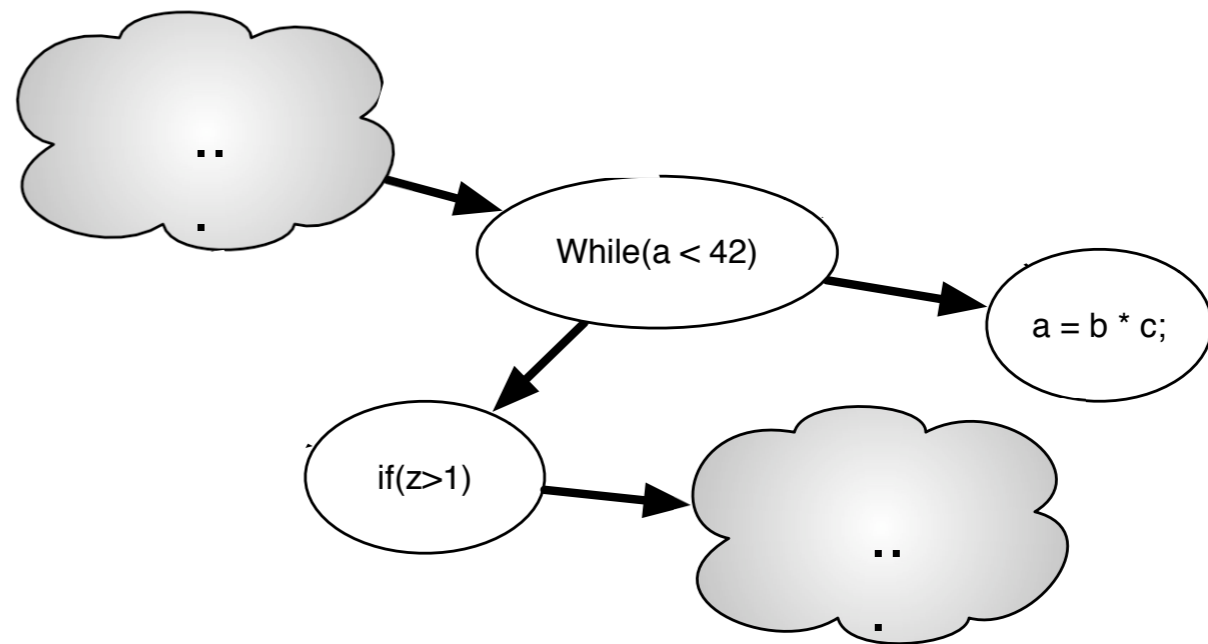
If - statement



Dependency Graphs

- Multi Graph - composed of
 - Control Graph
 - Data Flow Graph

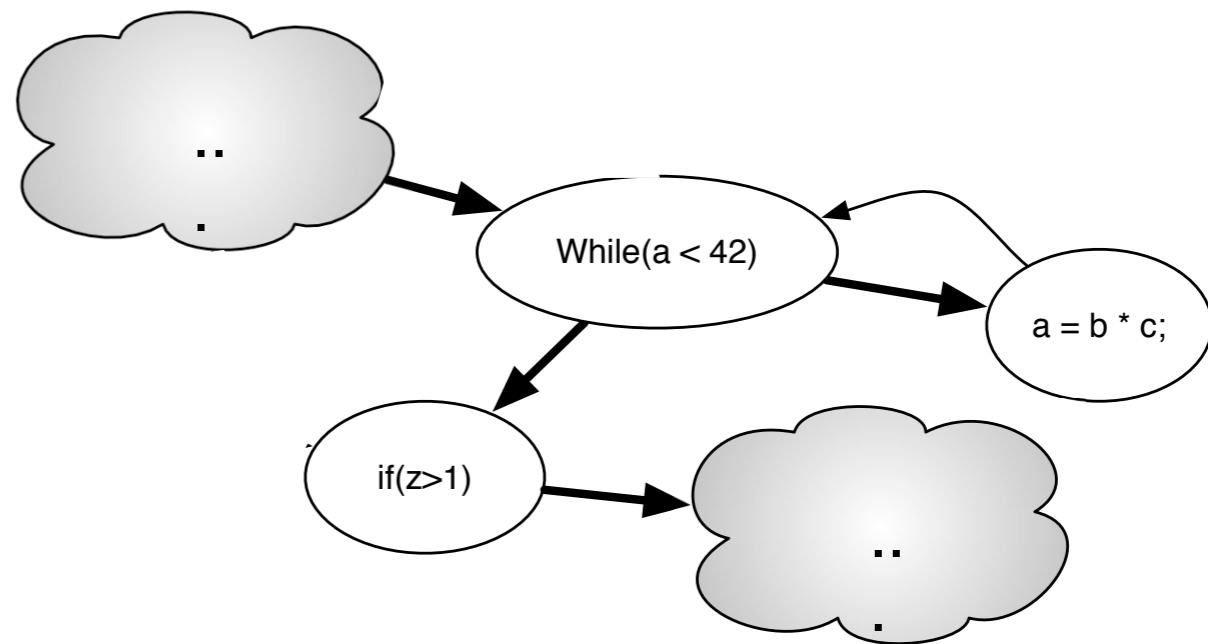
```
...  
while (a < 42)  
{  
    a = b * c;  
    if(z > 1)  
    {  
        ...  
    }  
}
```



Dependency Graphs

- Multi Graph - composed of
 - Control Graph
 - Data Flow Graph

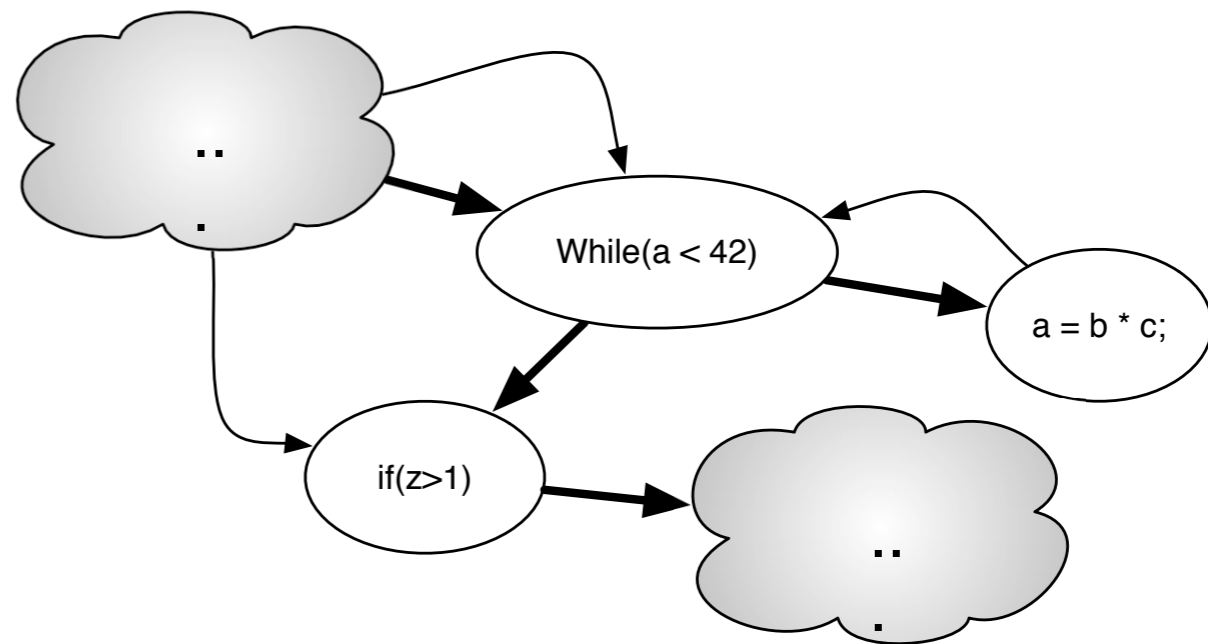
```
...  
while (a < 42)  
{  
    a = b * c;  
    if(z > 1)  
    {  
        ...  
    }  
}
```



Dependency Graphs

- Multi Graph - composed of
 - Control Graph
 - Data Flow Graph

```
...  
while (a < 42)  
{  
    a = b * c;  
    if(z > 1)  
    {  
        ...  
    }  
}
```



Example Function Dependency Graph

- Identify place of relevance
- and irrelevant code
- Inter-procedural slicing

[S. Horwitz, T. Reps, and D. Binkley]

```
int x = 0;
int z = 0;

int foo(int a, int b)
{
    while(a < 42)
    {
        a = b * x;
        if(z > 1)
        {
            z--;
        }
    }
    return a;
}

void bar()
{
    z = 42;
    x = foo(x,z);
}
```

Example Function Dependency Graph


- Identify place of relevance
- and irrelevant code
- Inter-procedural slicing

[S. Horwitz, T. Reps, and D. Binkley]

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Example Function Dependency Graph

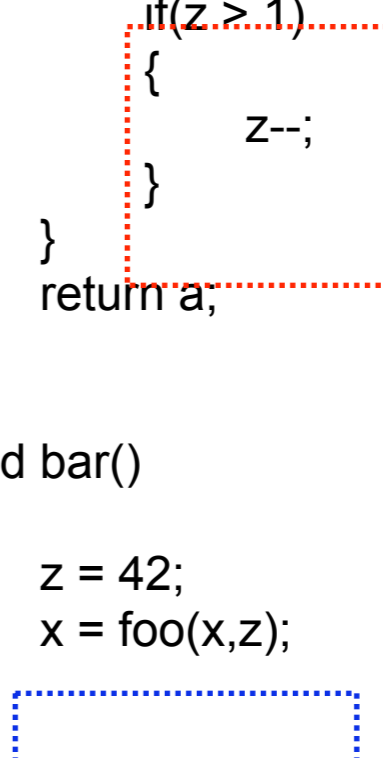
- Identify place of relevance
- and irrelevant code
- Inter-procedural slicing

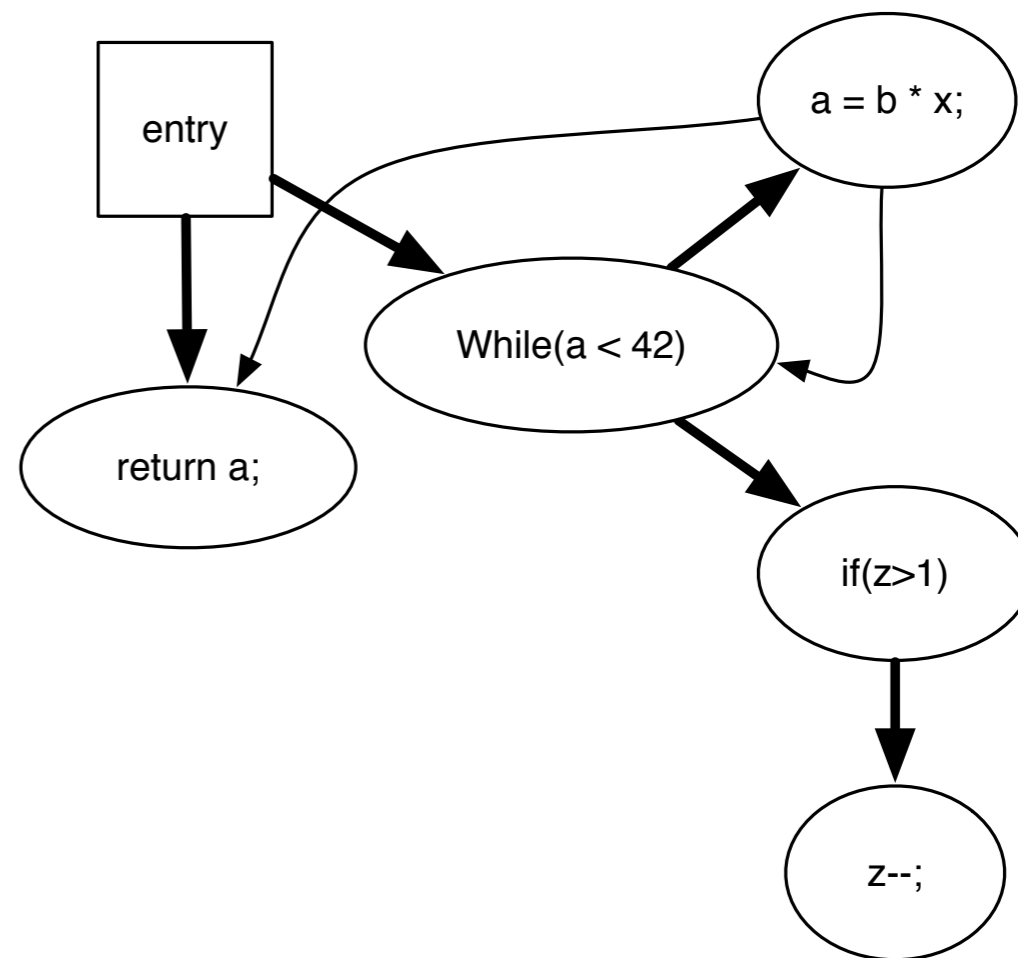
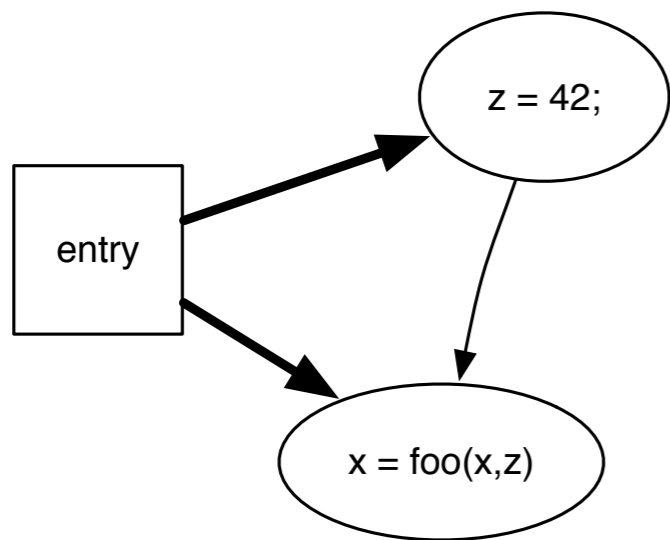
[S. Horwitz, T. Reps, and D. Binkley]

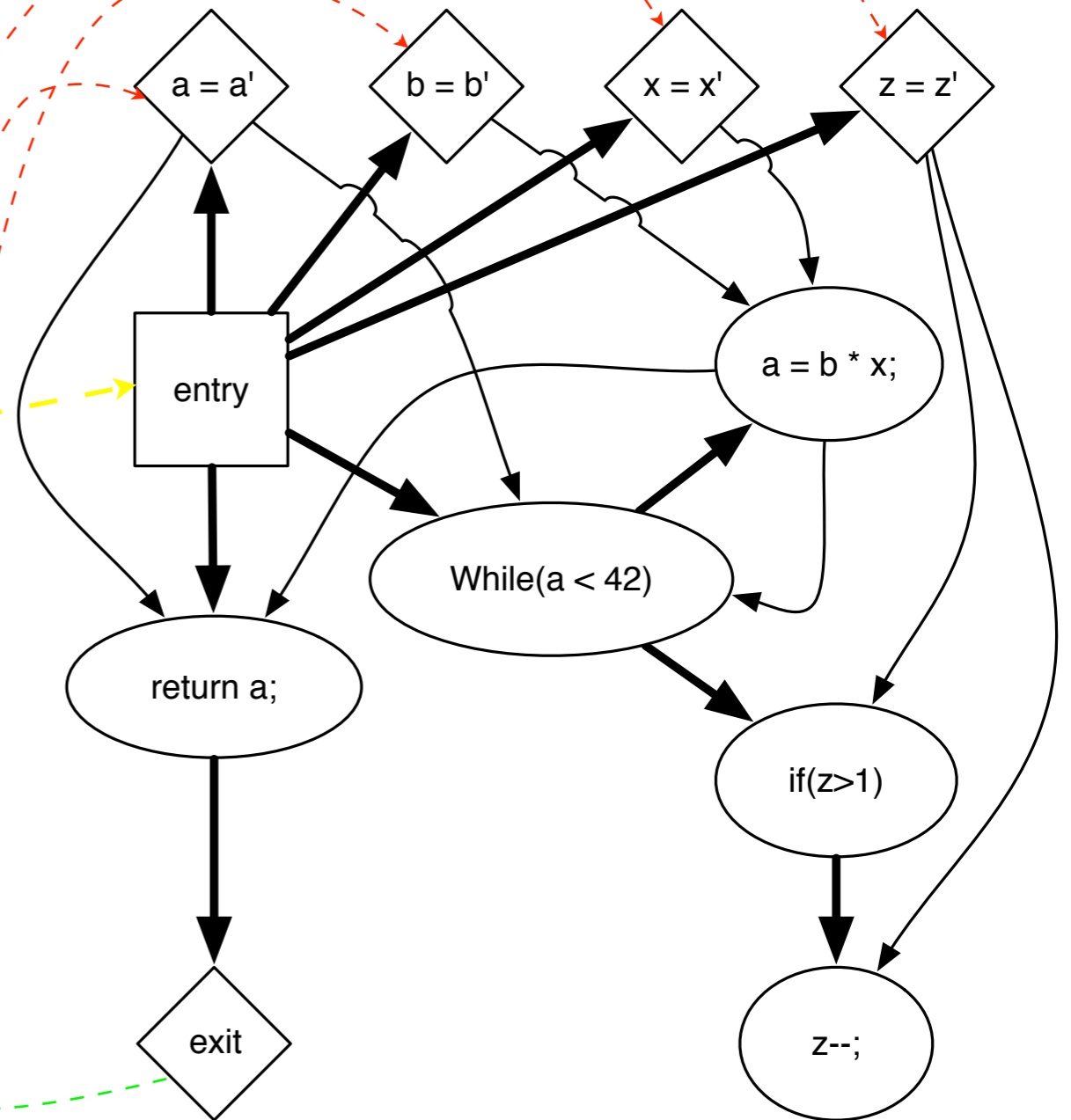
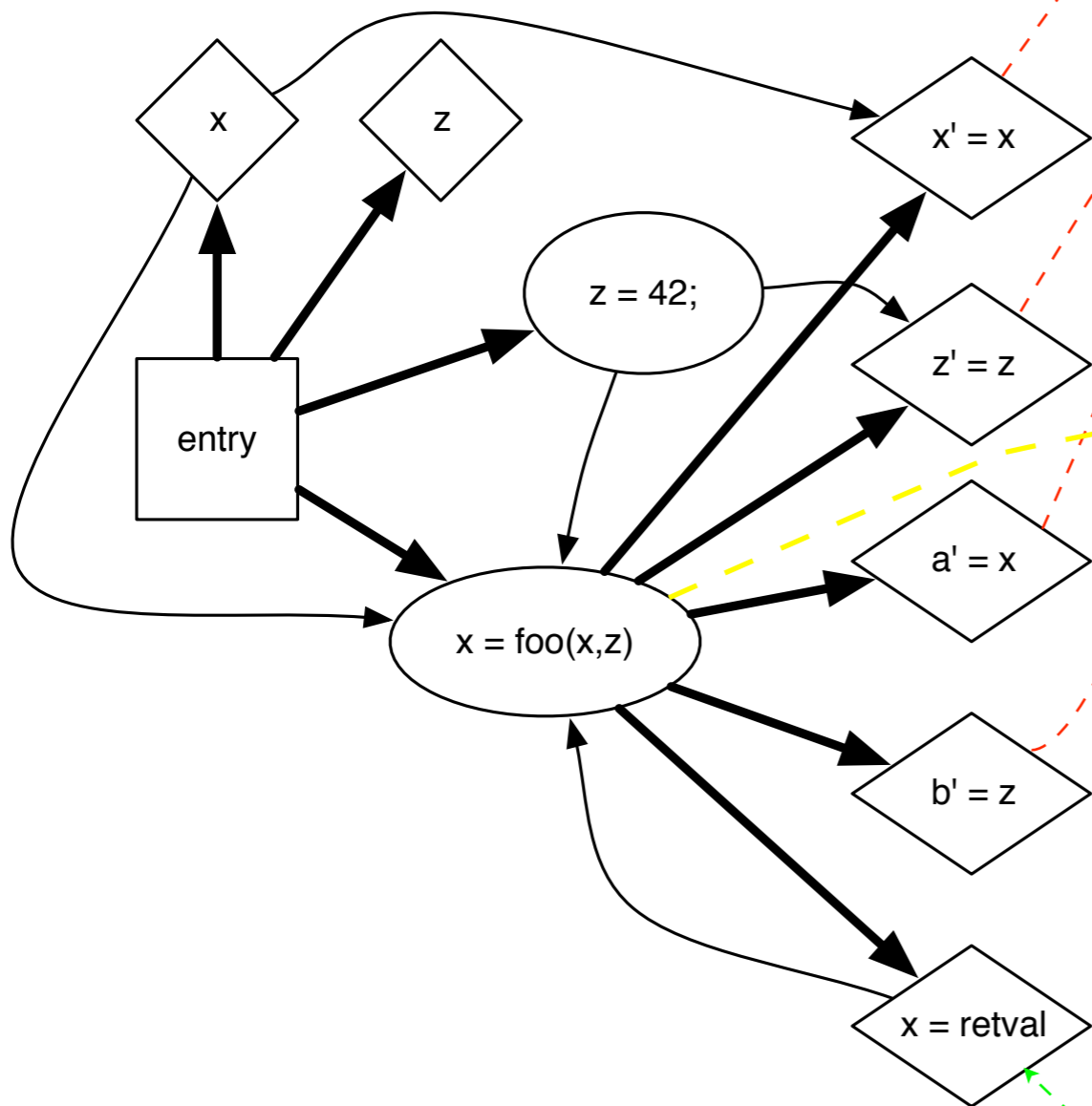
```
int x = 0;
int z = 0;

int foo(int a, int b)
{
    while(a < 42)
    {
        a = b * x;
        if(z > 1)
        {
            z--;
        }
    }
    return a;
}

void bar()
{
    z = 42;
    x = foo(x,z);
}
```

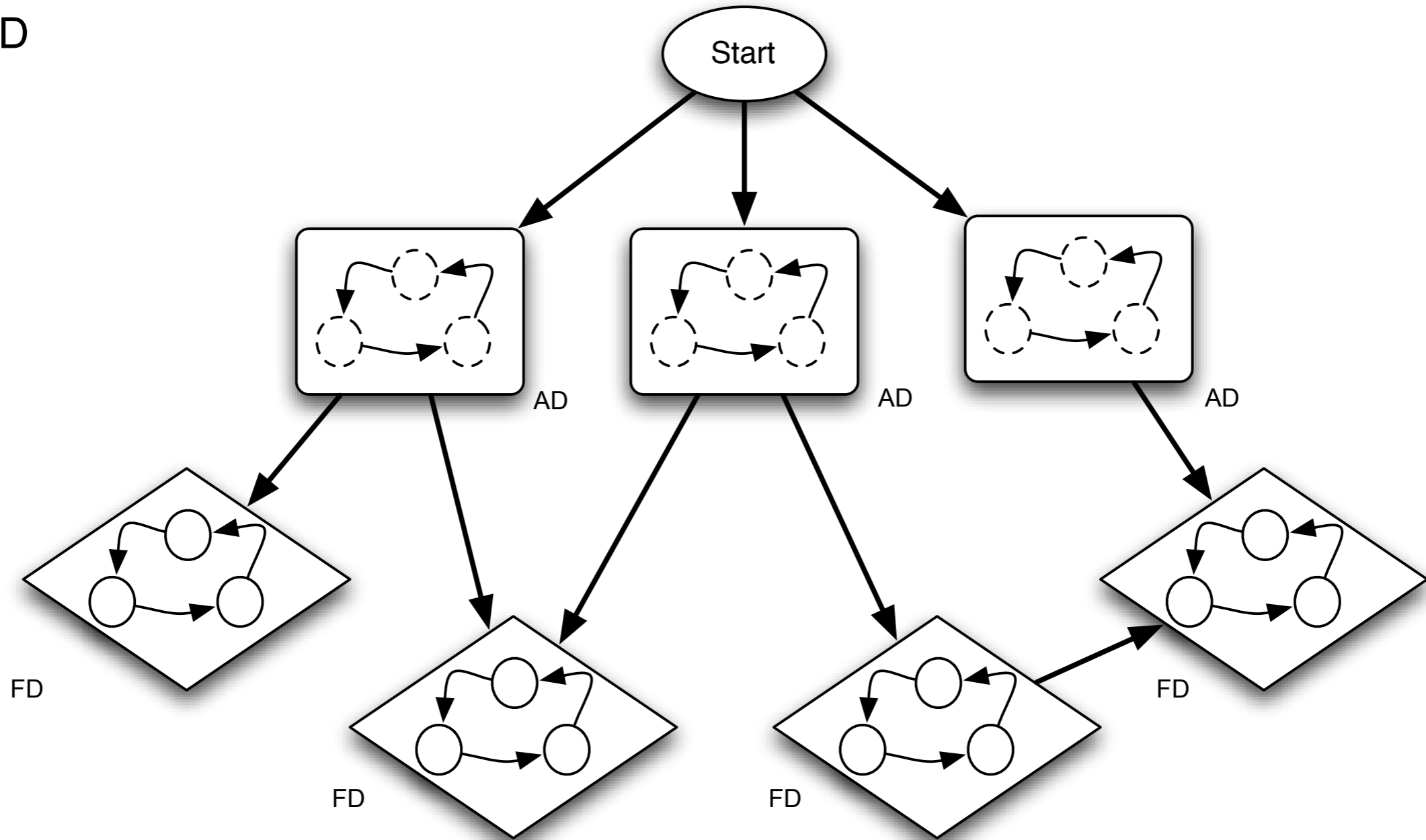






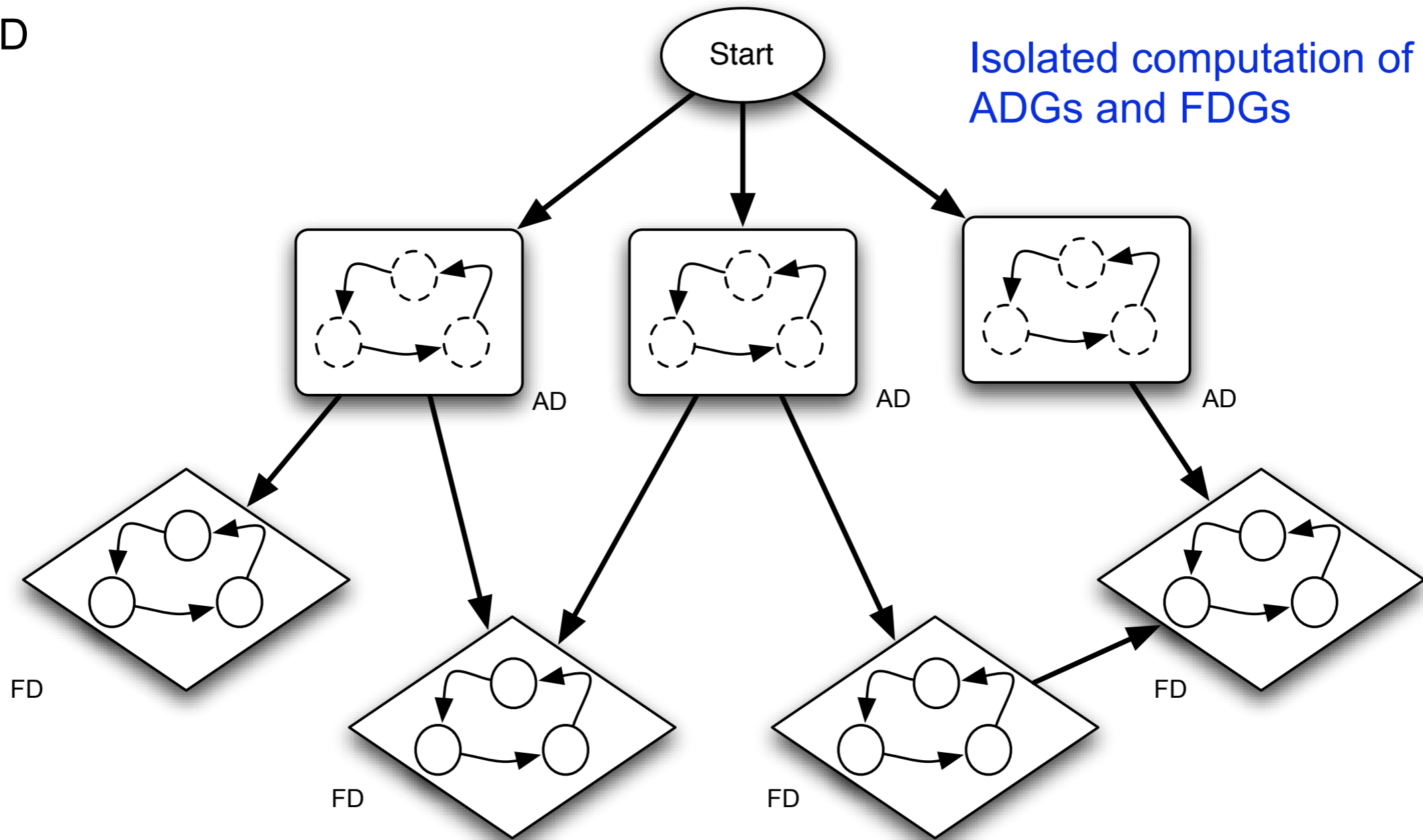
System Dependency Graph

SD



System Dependency Graph

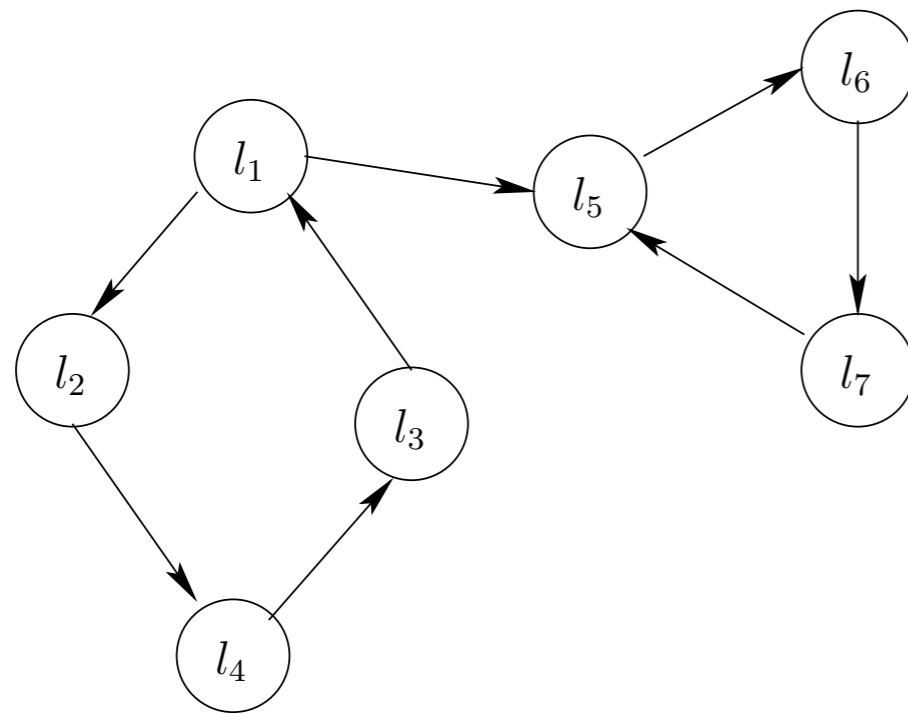
SD



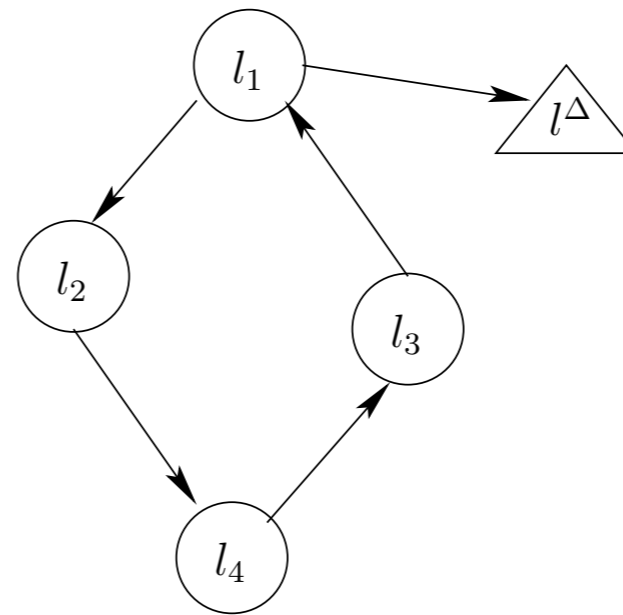
Slicing Extended TA

- Starts at a point of interest e.g. a location in the TA
- Search backwards in the SDG (marking pp)
 - Computes the fixed-point of dependencies in the ADG
 - Searches backward in the called FDGs
- Delete all un-marked statements.

Conservative Automata slicing

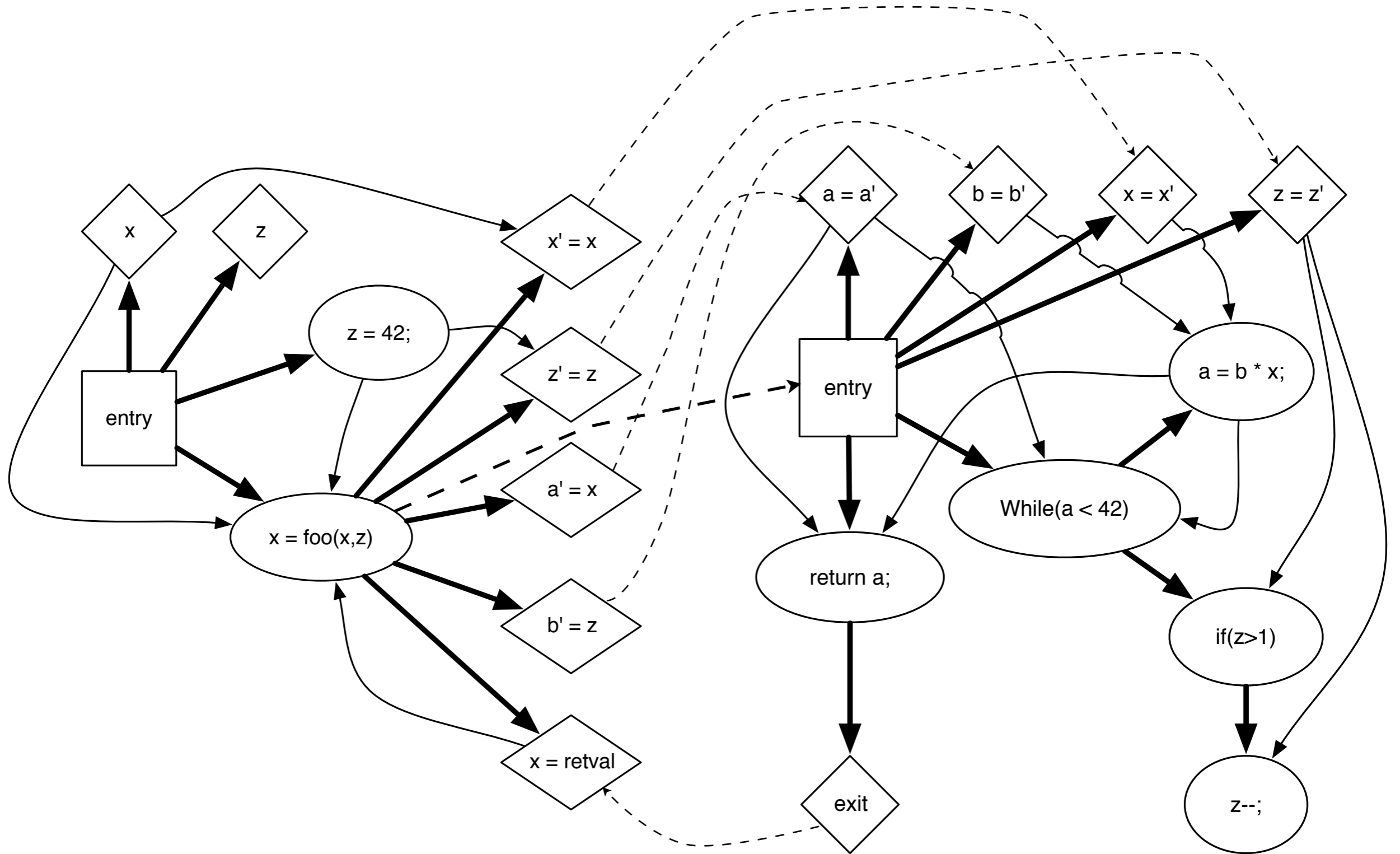


(a) Example Automata

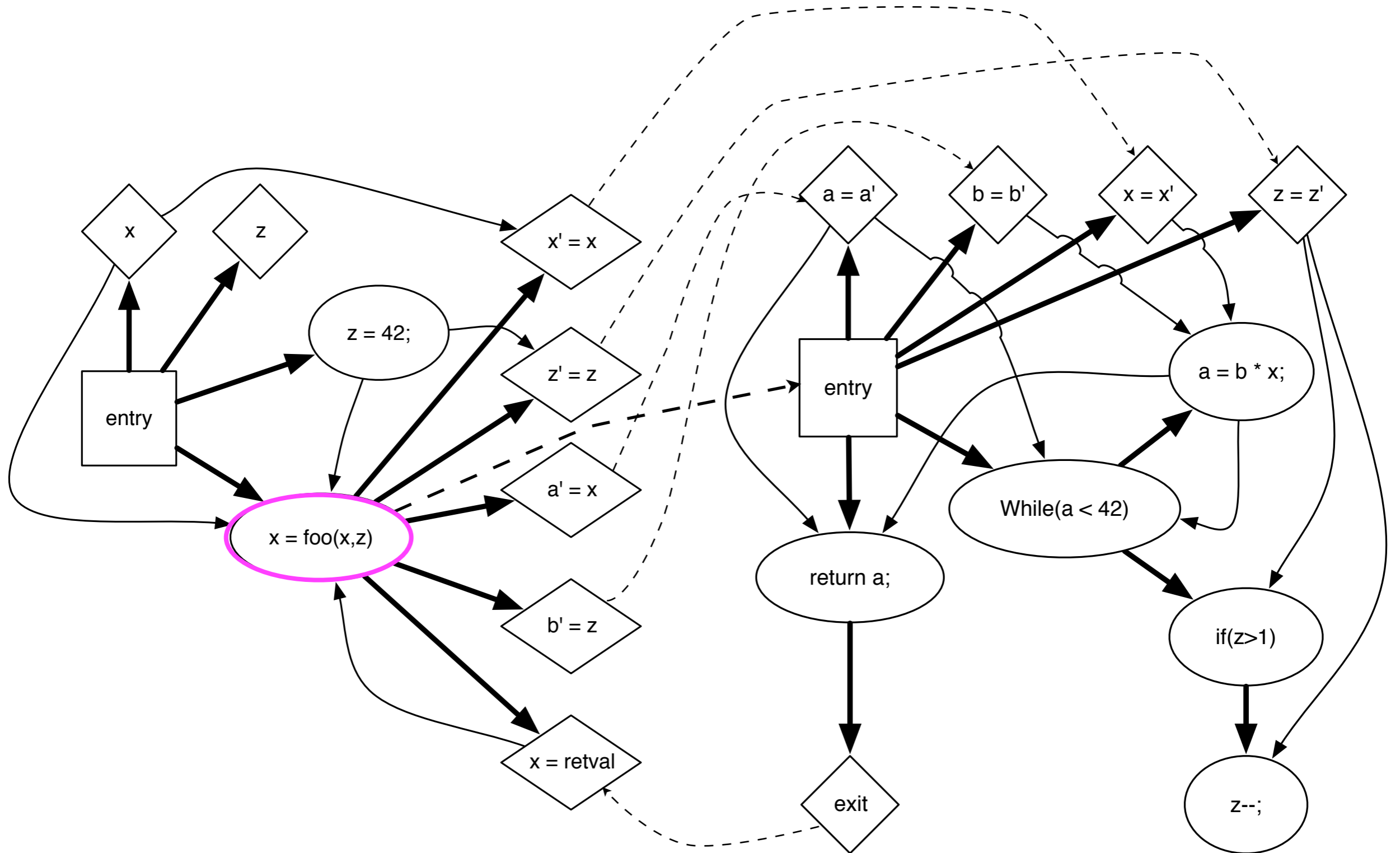


(b) Automata with sink

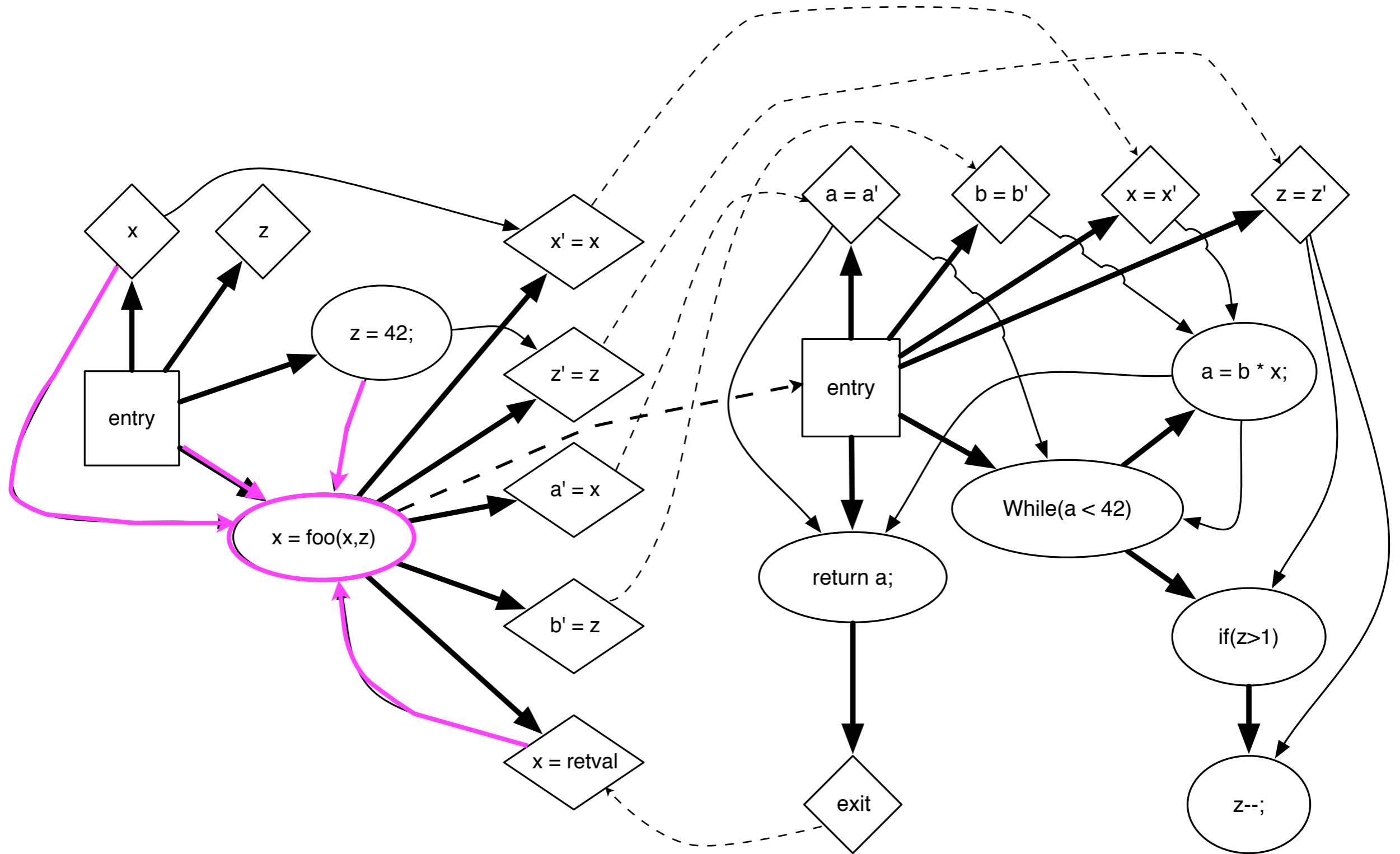
Traversal of imperative code



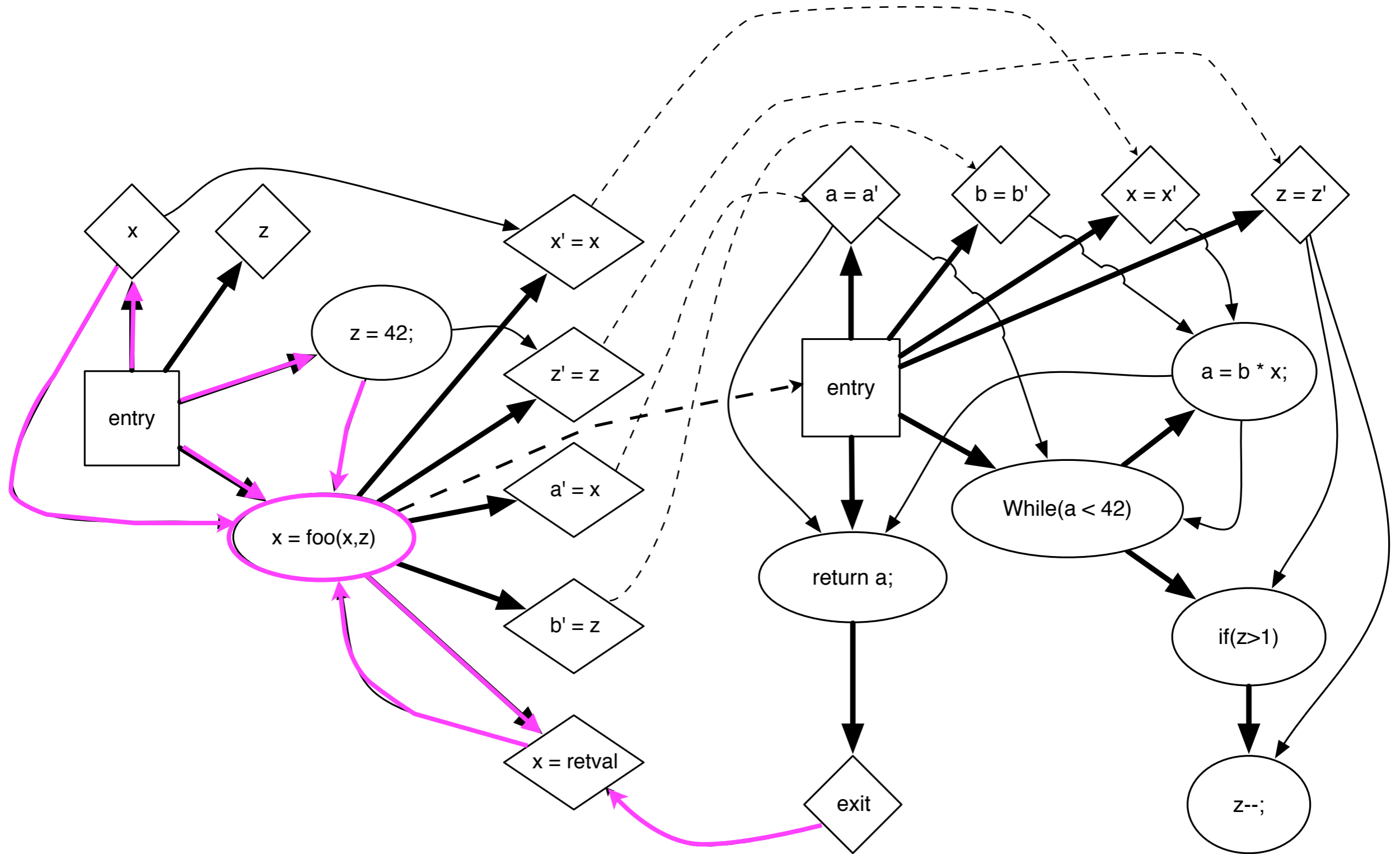
Traversal of imperative code



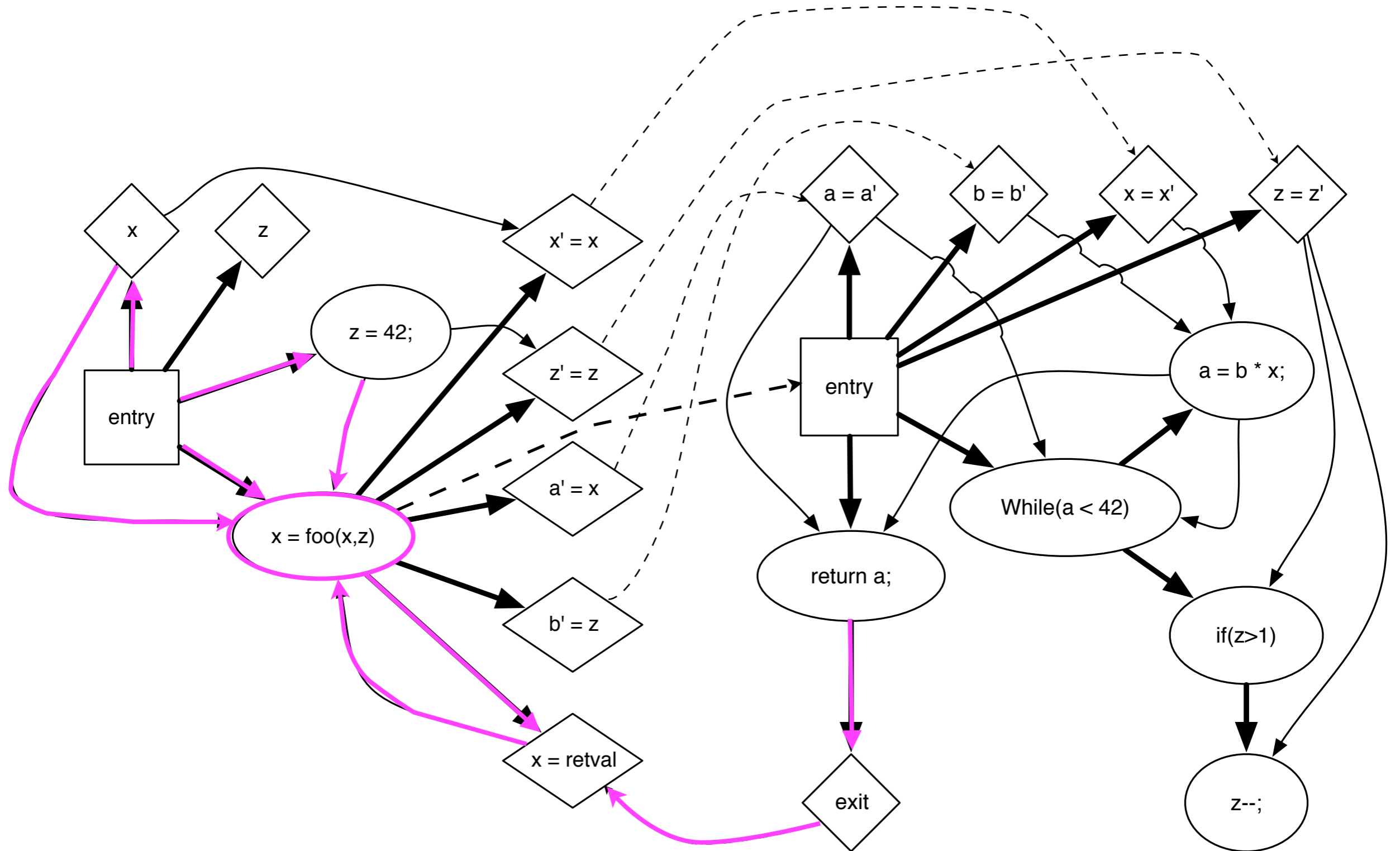
Traversal of imperative code



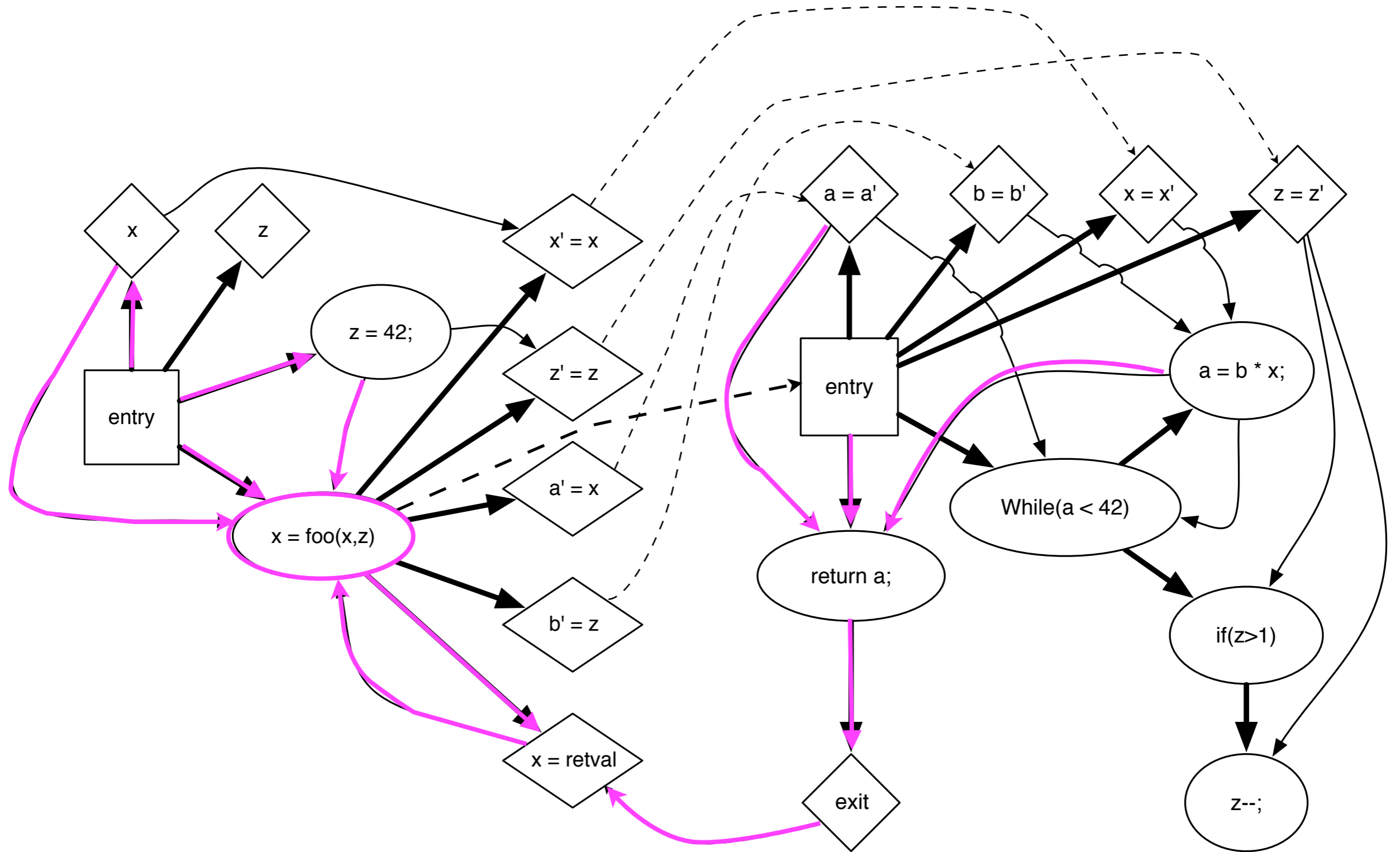
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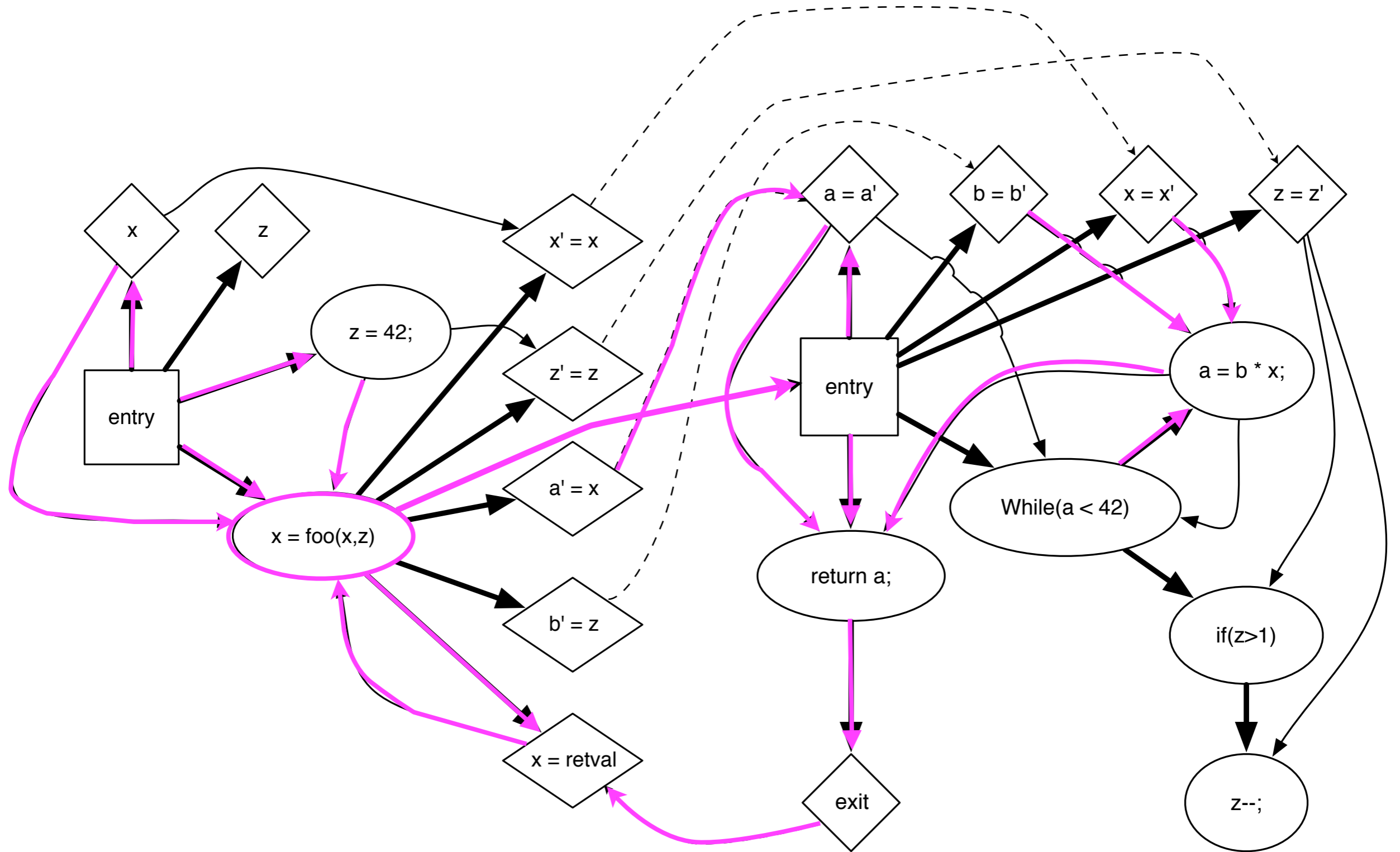
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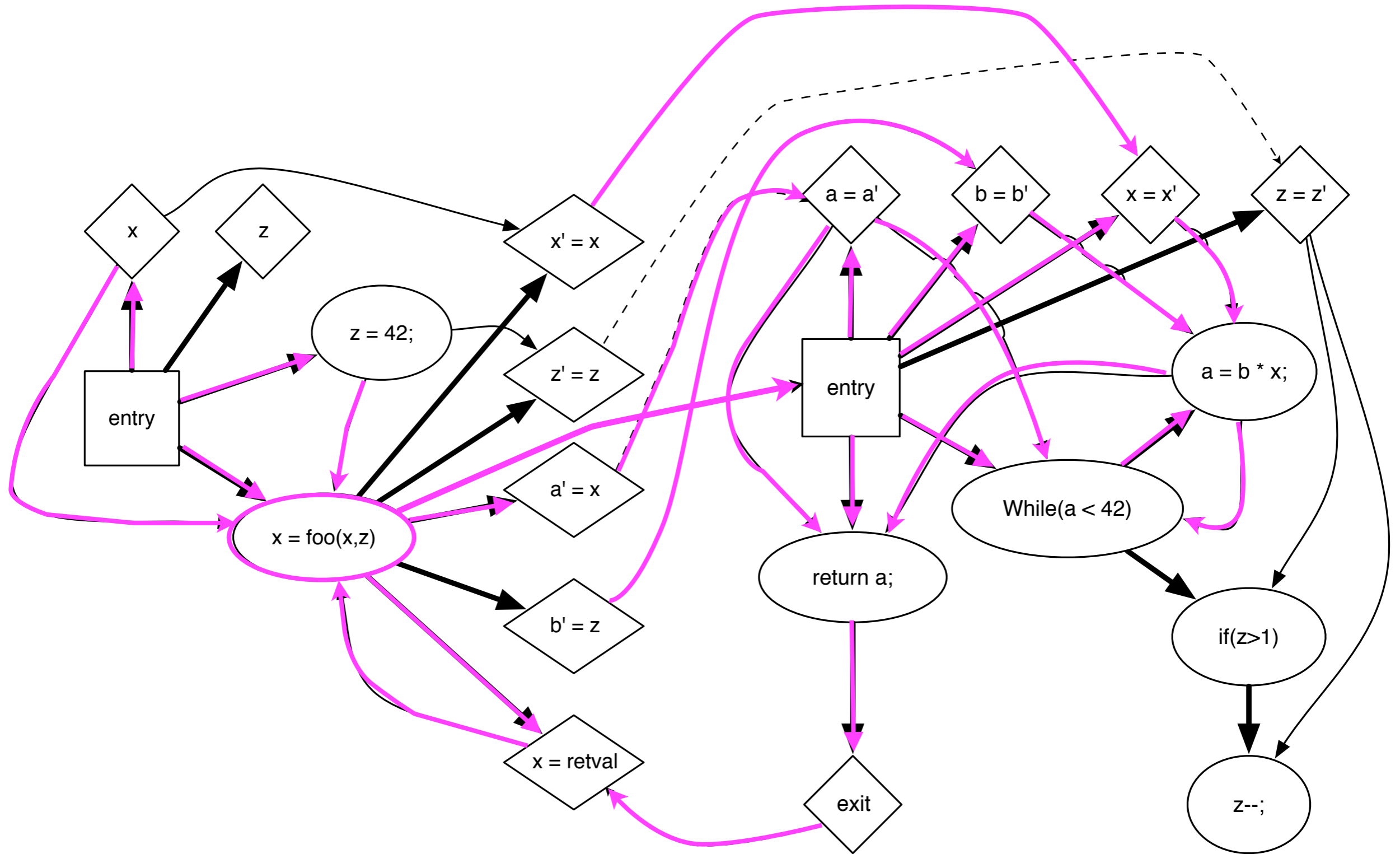
Traversal of imperative code



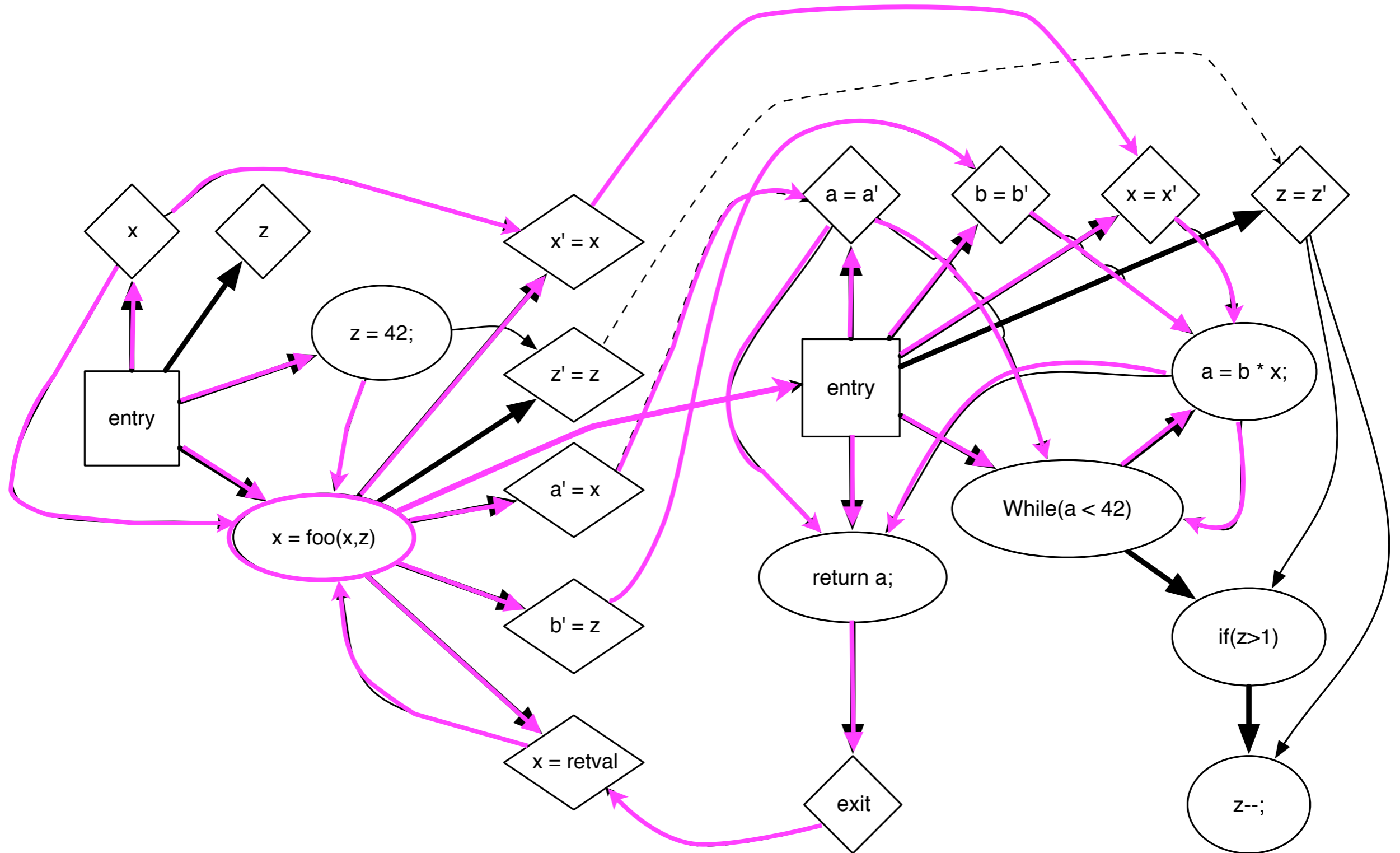
Traversal of imperative code



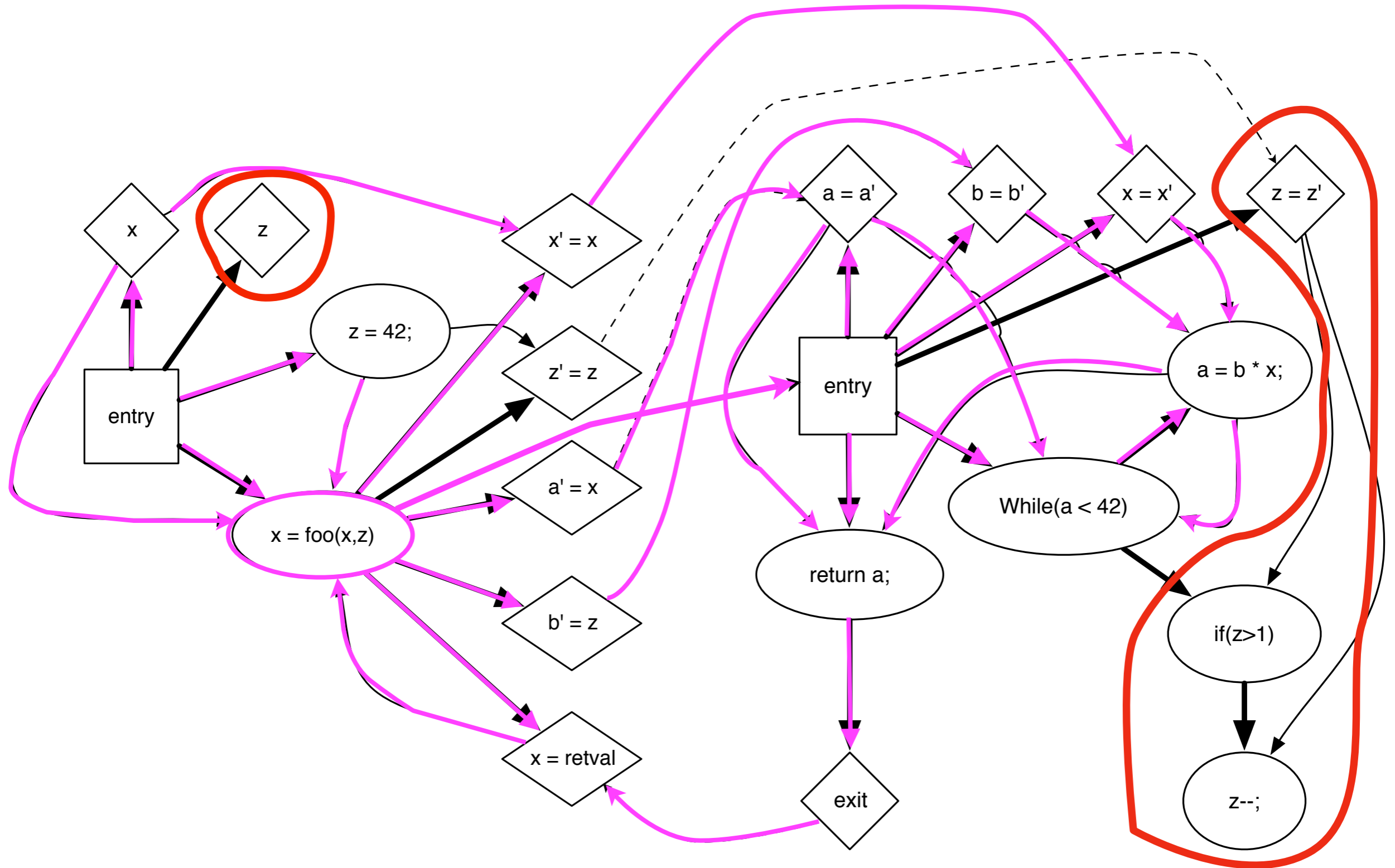
Traversal of imperative code



Traversal of imperative code



Traversal of imperative code



Bisimulation based Correctness

- Reachability preserving slices (CTL)

Lemma 1. *If $s R_\varphi s'$ for some $E\Diamond\varphi$ -Bisimulation then:*

$$s \models E\Diamond\varphi \iff s' \models E\Diamond\varphi$$

Theorem 1. *The relation $\simeq \subseteq S \times S'$ is a $E\Diamond\varphi$ -Bisimulation between two structures $M = (S, \mathcal{I})$ and $M' = (S', \mathcal{I}')$.*

Empirical results

	Mapper Example				
<i>Deadlock free</i>	VT	MU	SS	NS	NV
Before Slicing	N/A	4GB+	85587630+	12	6
After Slicing	11.12sec *	66572KB	786391	6	3
<i>After Fix</i>	VT	MU	SS	NS	NV
Before Slicing	0.11sec	2862KB	2074	12	6
After Slicing	0.10sec	2852KB	199	6	3

	Train-Gate Example				
<i>Deadlock free</i>	VT	MU	SS	NS	NV
Before Slicing	N/A	4GB+	77636326+	34	14
After Slicing	0.2sec	2848KB	413	28	10
<i>Train may cross</i>	VT	MU	SS	NS	NV
Before Slicing	0.11sec	2856KB	14	34	14
After Slicing	0.10sec	2848KB	14	28	10

VT = Verification Time, MU = Memory Usage, SS = Symbolic States Explored, NS = Number of Statements, NV = Number of Variables

Empirical results

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VT = Verification Time, MU = Memory Usage, SS = Symbolic States Explored, NS = Number of Statements, NV = Number of Variables

Conclusion

- Slicing is highly beneficial for UPPAAL
- Conservative - reachability preserving algorithm
 - Prototype implementation
- Supports iterative Development / Design
- Side-effect: “encourage” new users

Future

- Further Experiments
- Consolidation of Library (production ready code)
- Complete SSA Form Transformation (C-code)
- Integration in UPPAAL
- Integrate value range propagation (on int vars)

- Visualization of slices in UPPAALs GUI
- Research “Manual” Slicing

Thank you

- Summary:
 - Applied the SDG for imperative code and TA
 - Proof that slicing preserves (CTL) reachability
 - Prototype implementation
 - Generic static analysis library for Uppaal
 - Future work (highlights)
 - Further empirical studies
 - Consolidation of library code