A graph model for data and workflow provenance

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Provenance in ...

- Databases
  - Mainly for (nested) relational model
  - Where-provenance ("source location")
  - Lineage, why ("witnesses")
  - How/semiring model
  - Relatively formal
- Workflows
  - Many different systems
  - Many different models
    - (converging on OPM?)
  - Graphs/DAGs
  - Relatively informal

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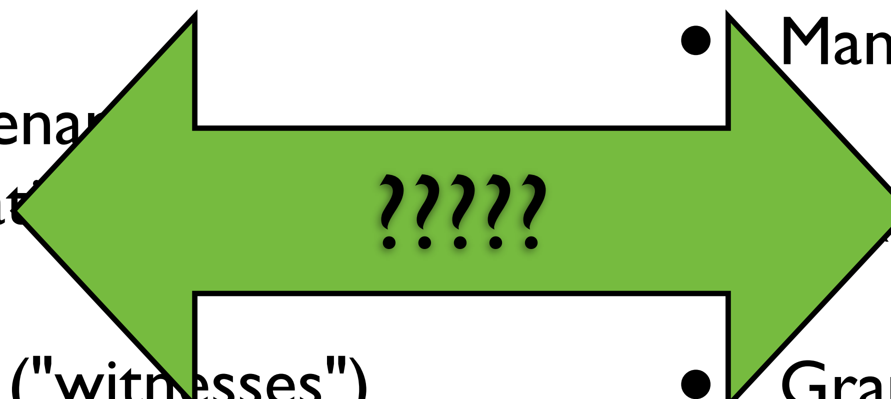

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  - Many different models
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This talk

- Relate database & workflow "styles"
- Develop a common graph formalism
- Need a common, expressive language that
  - supports many database queries
  - describes some (simple) workflows

Previous work

- Dataflow calculus (DFL), based on nested relational calculus (NRC)
  - Provenance "run" model by Kwasnikowska & Van den Bussche (DILS 07, IPAW 08)
- "Provenance trace" model for NRC
  - by (Acar, Ahmed & C. '08)
- Open Provenance Model (bipartite graphs)
  - (Moreau et al. 2008-9), used in many WF systems

NRC/DFL background

- A very simple, functional language:
  - basic functions +, *,... & constants `0,1,2,3...`
  - variables `x,y,z`
  - pair/record types `(A:e,...,B:e)`, π_A`(e)`
  - **collection (set) types**
    - `{e,...}`   `e ∪ e`   `{e | x in e'}`   `∪e`

An example

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- Suppose R = {(1,2,3), (4,5,6), (9,8,7)}

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= sum {2,20}
```

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= sum { x * y | (x,y,z) in {(1,2,3), (4,5,6)}}

= sum {1 * 2, 4 * 5}

= sum {2,20}

= 22
```
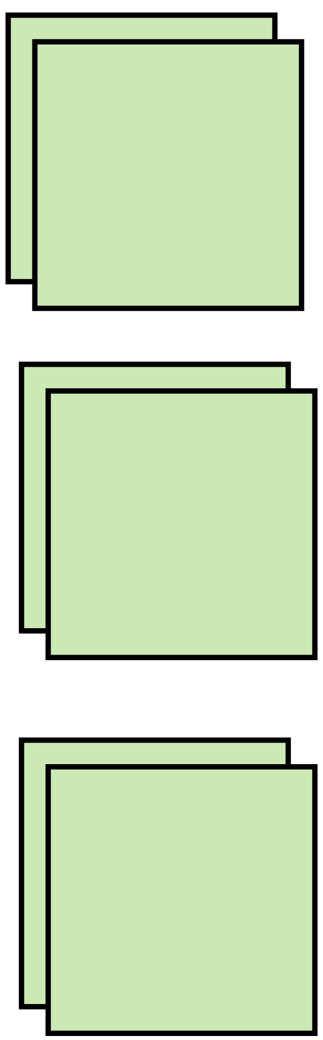

Another example

- In DFL, built-in functions / constants can be whole programs & files,
  - as in Provenance Challenge 1 workflow:

```
let WarpParams := {align_warp(img,hdr})
                   | (img,hdr) in Inputs} in
let Reslices := {reslice(wp)
                 | wp in WarpParams} in
softmean(Reslices)
```

Goal: Define "provenance graphs" for DFL



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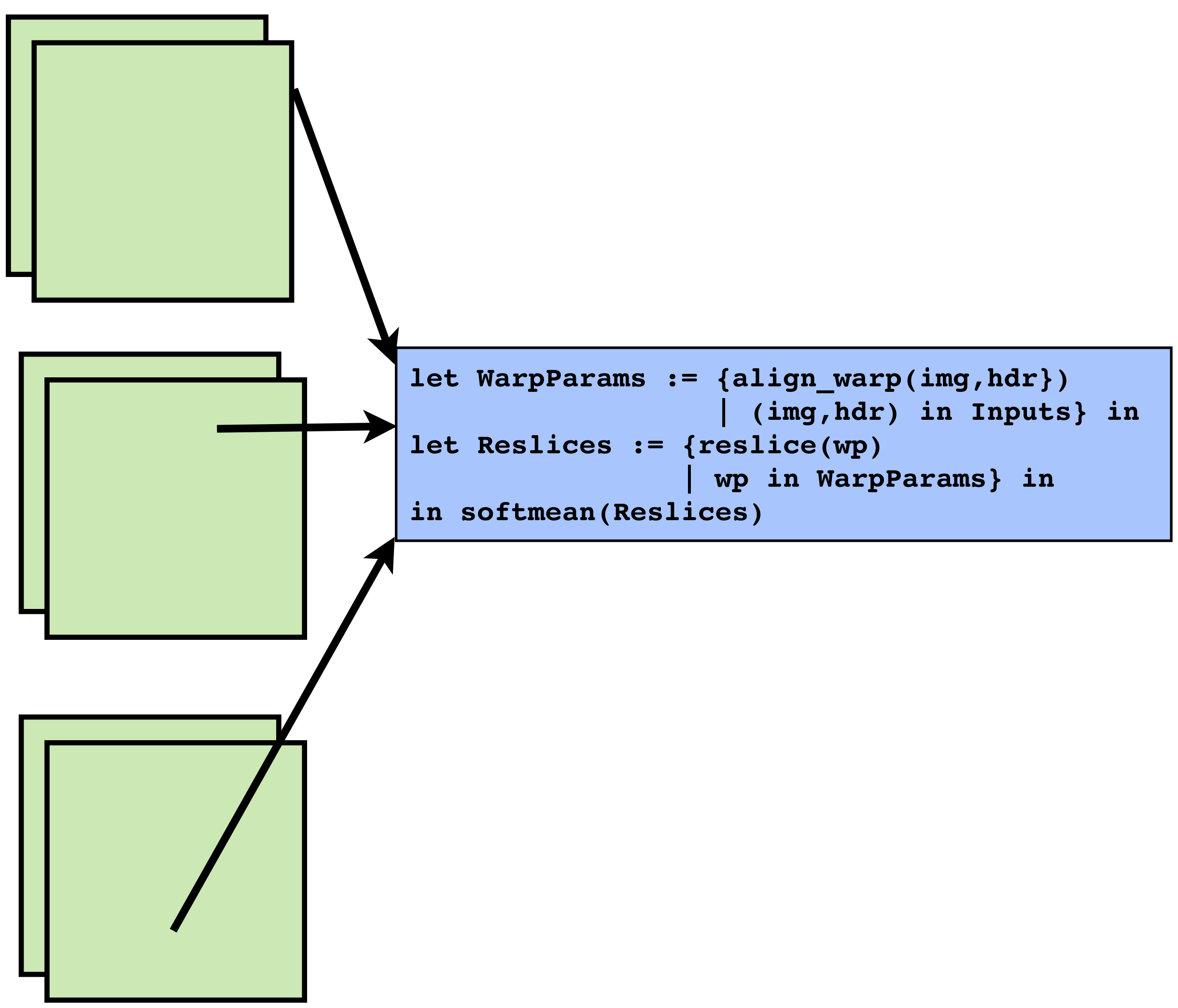

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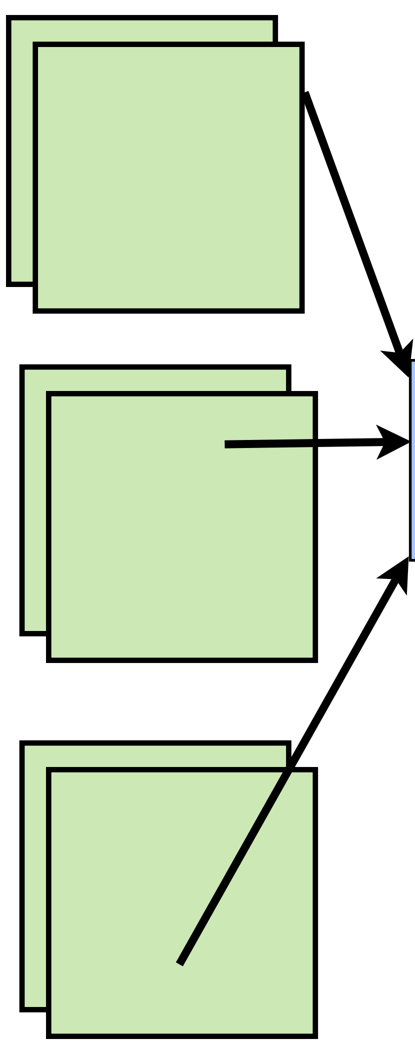

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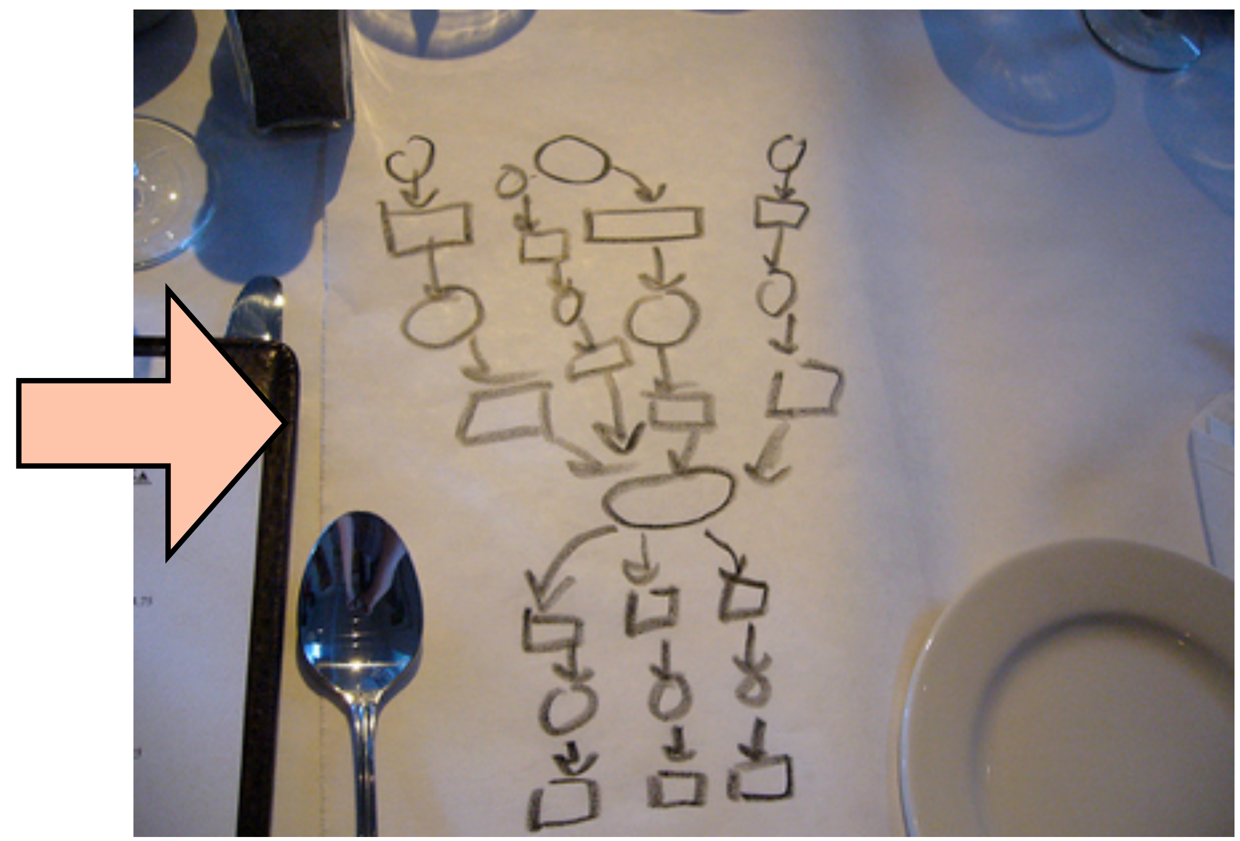

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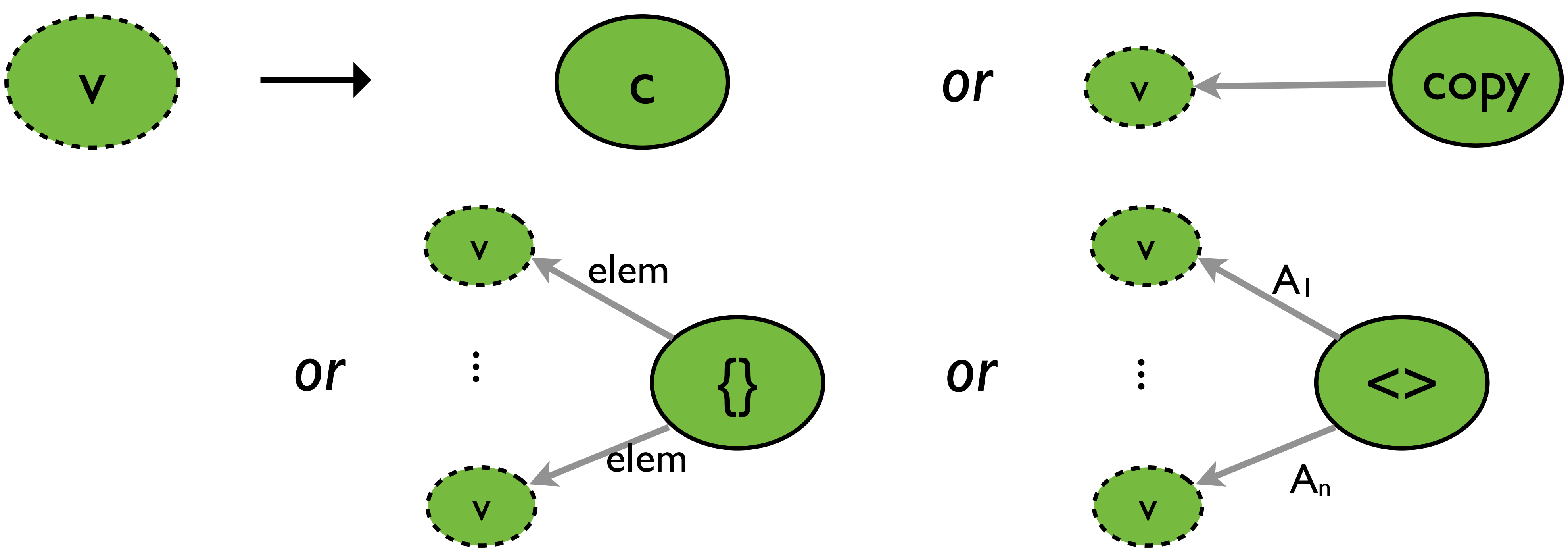
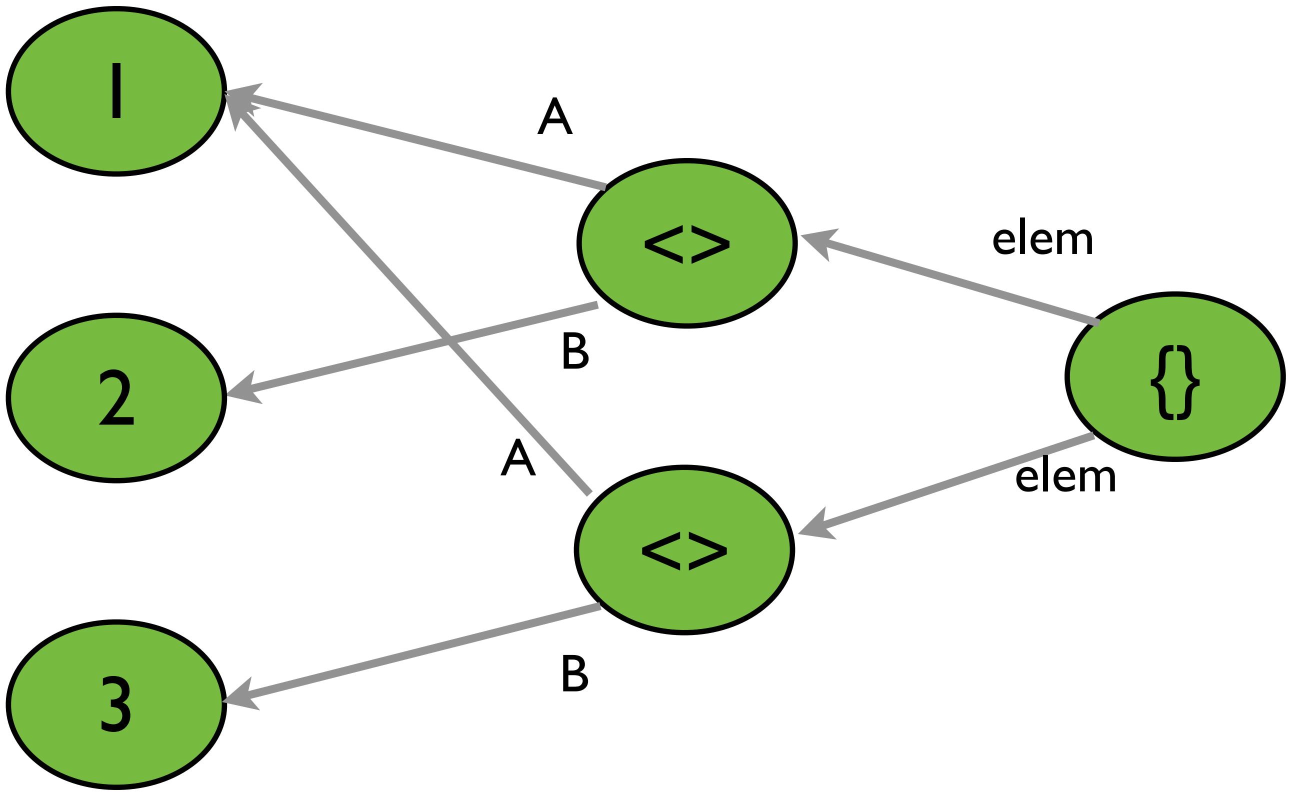
First step: values

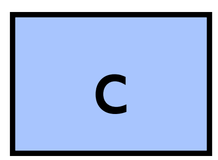


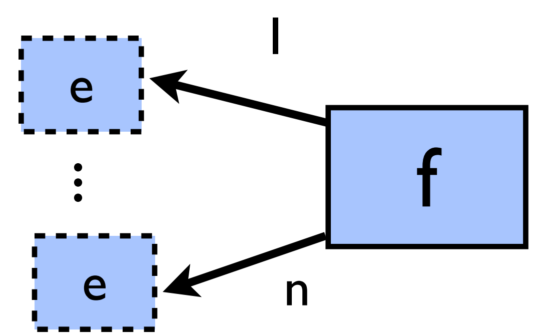
Example value



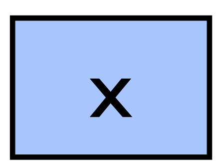
Next step: evaluation nodes ("process")

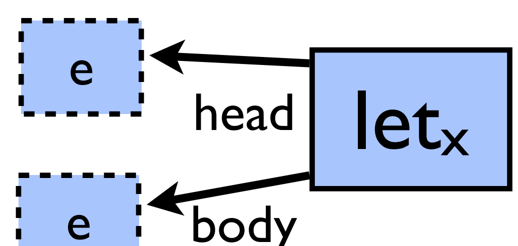
Constants, primitive functions





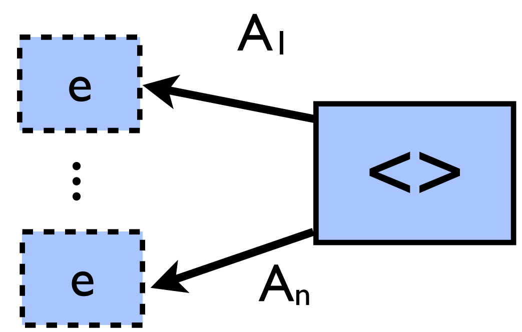
Variables & temporary bindings



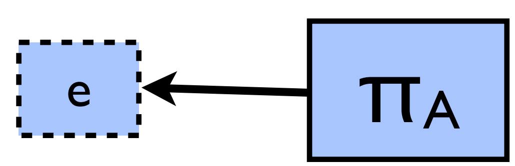


Pairing

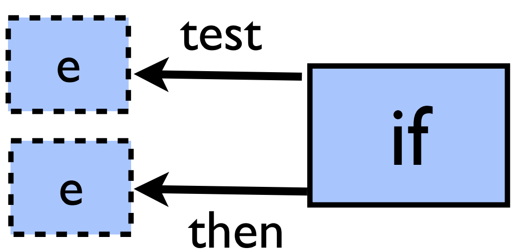
Record building

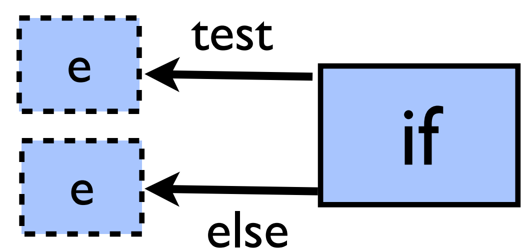


Field lookup



Conditionals

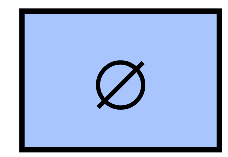




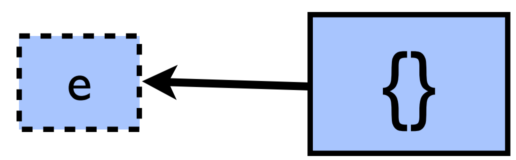
Note: Only taken branch is recorded

Sets: basic operations

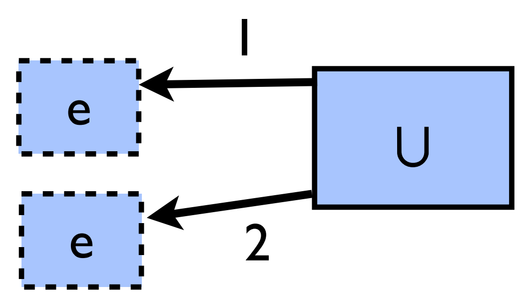
Empty set



Singleton

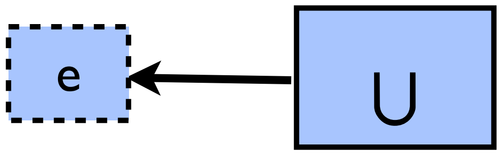


Union

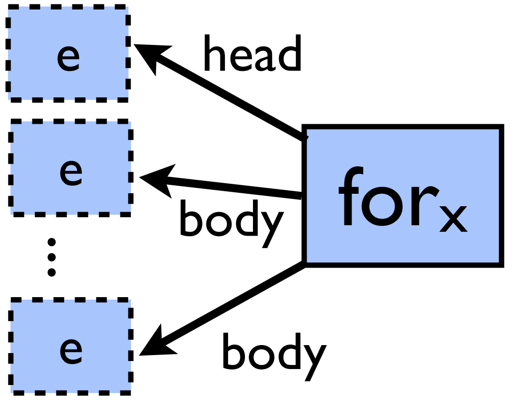


Sets: complex operations

Flattening

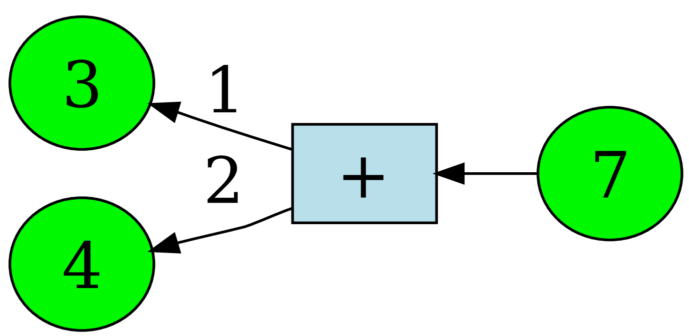


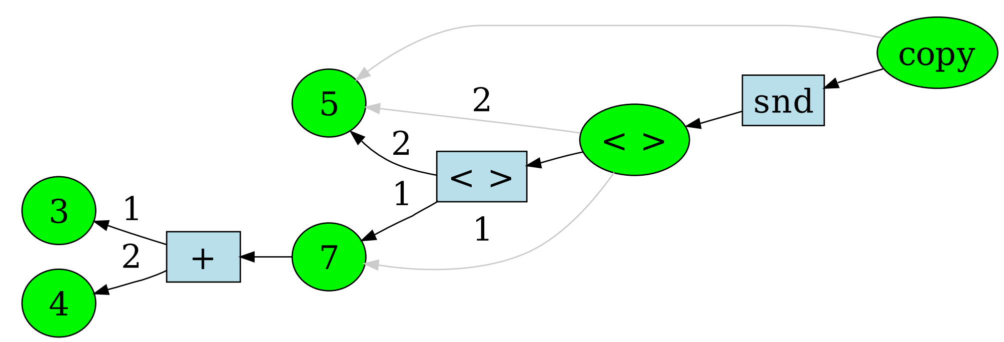
Iteration

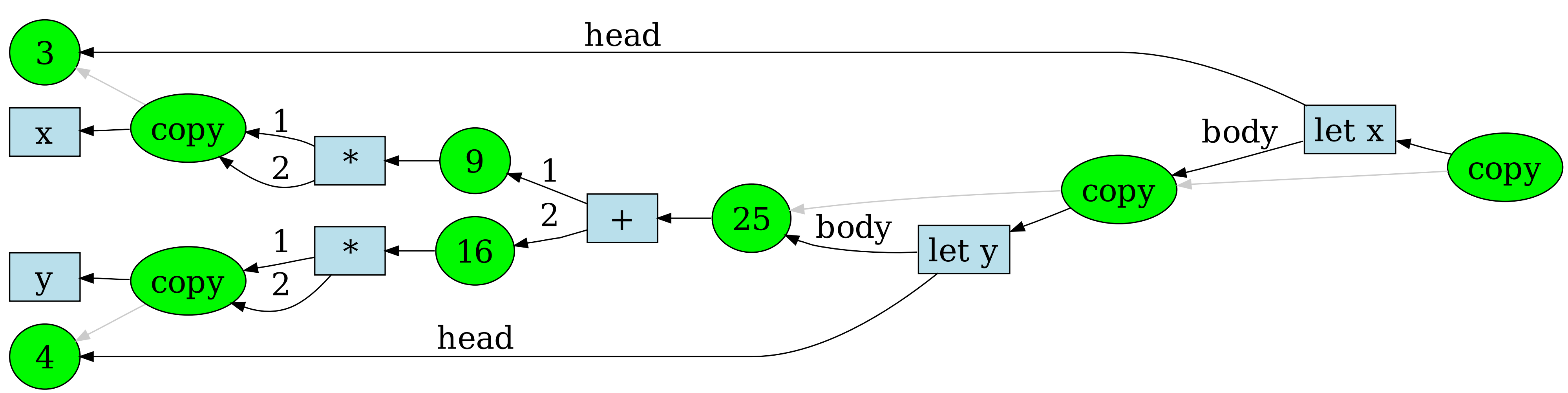


Provenance graphs

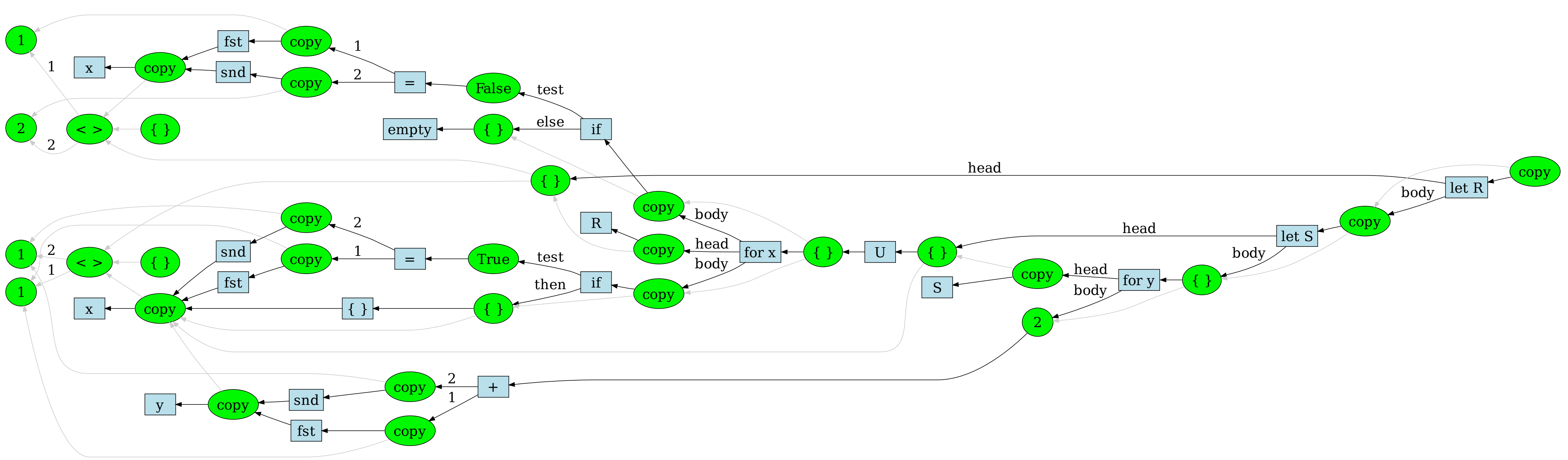
- are graphs with "both value and evaluation structure"



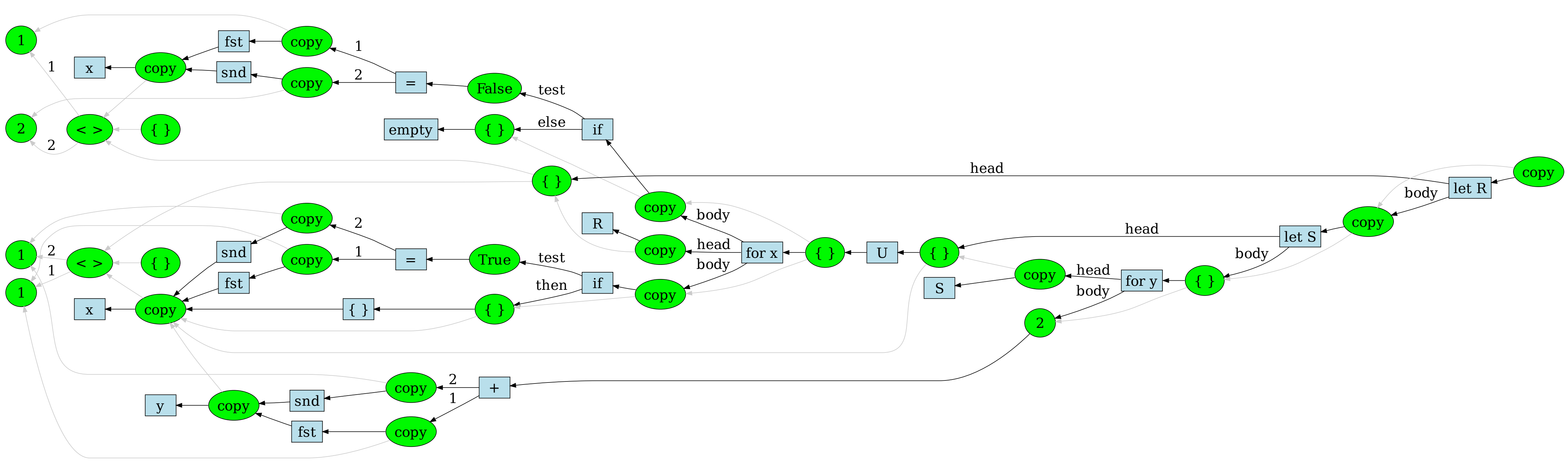




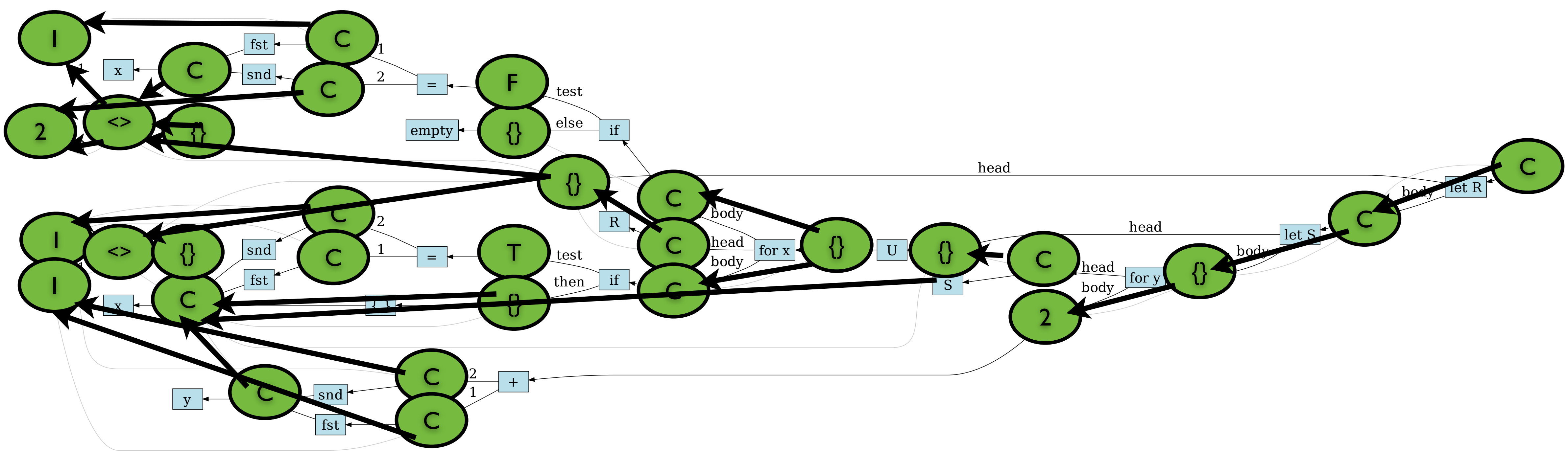
A bigger example



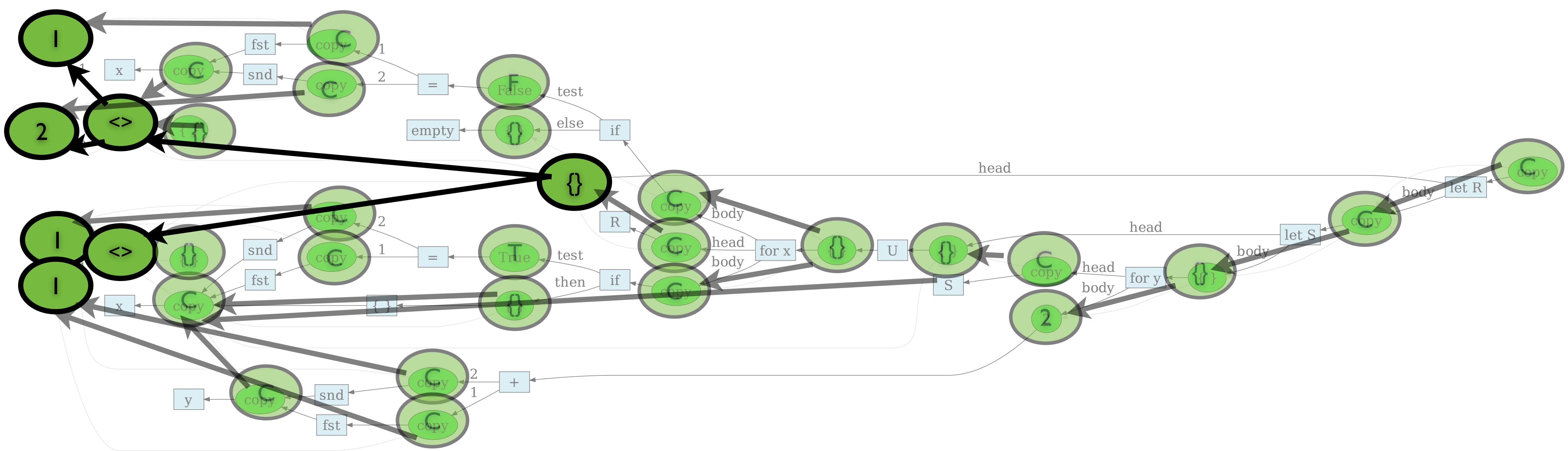
Value structure



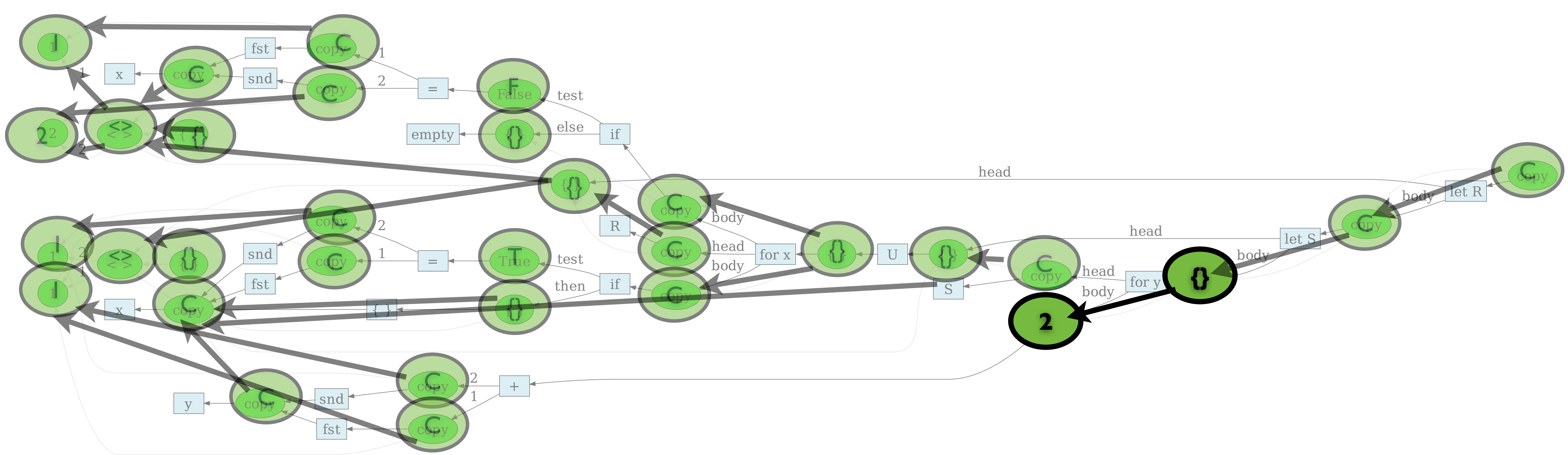
Value structure



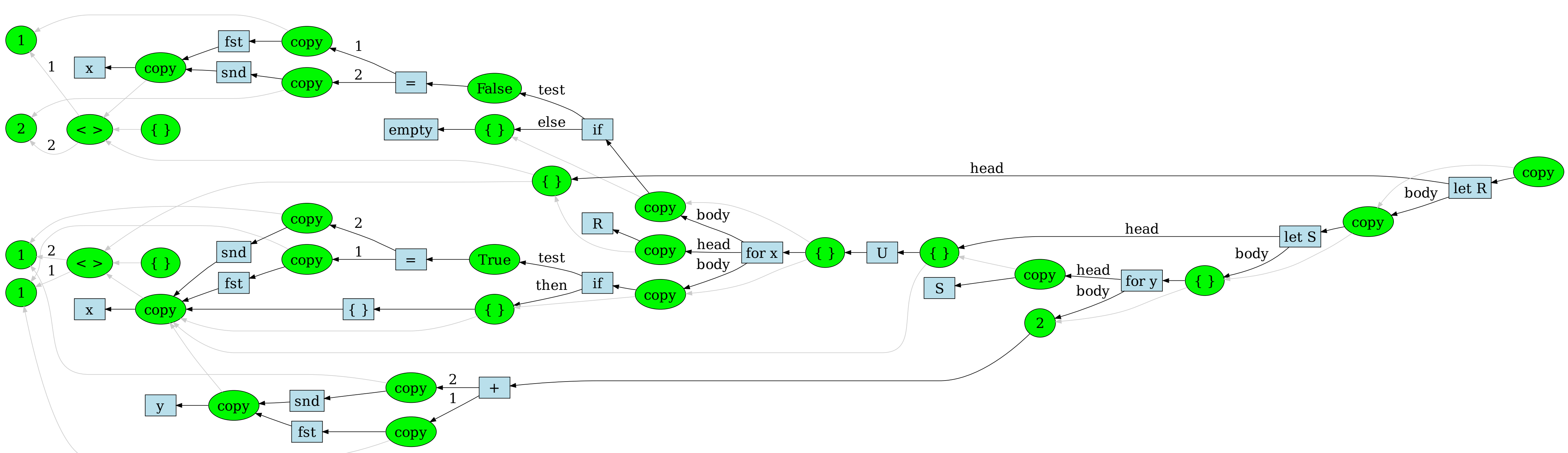
Input values



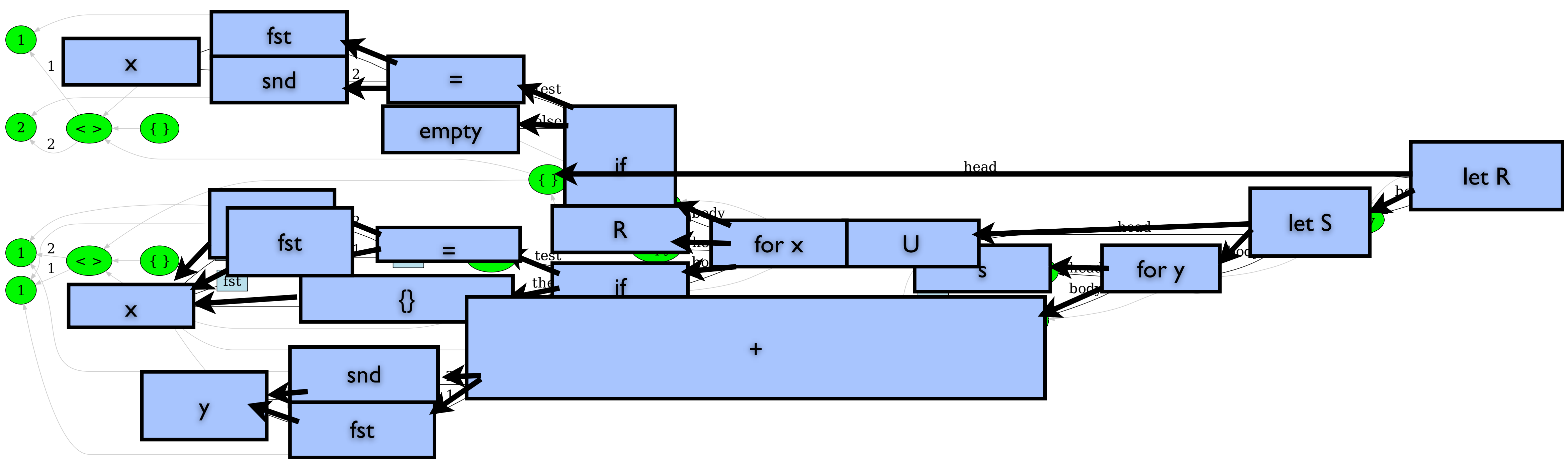
Return value



Expression structure

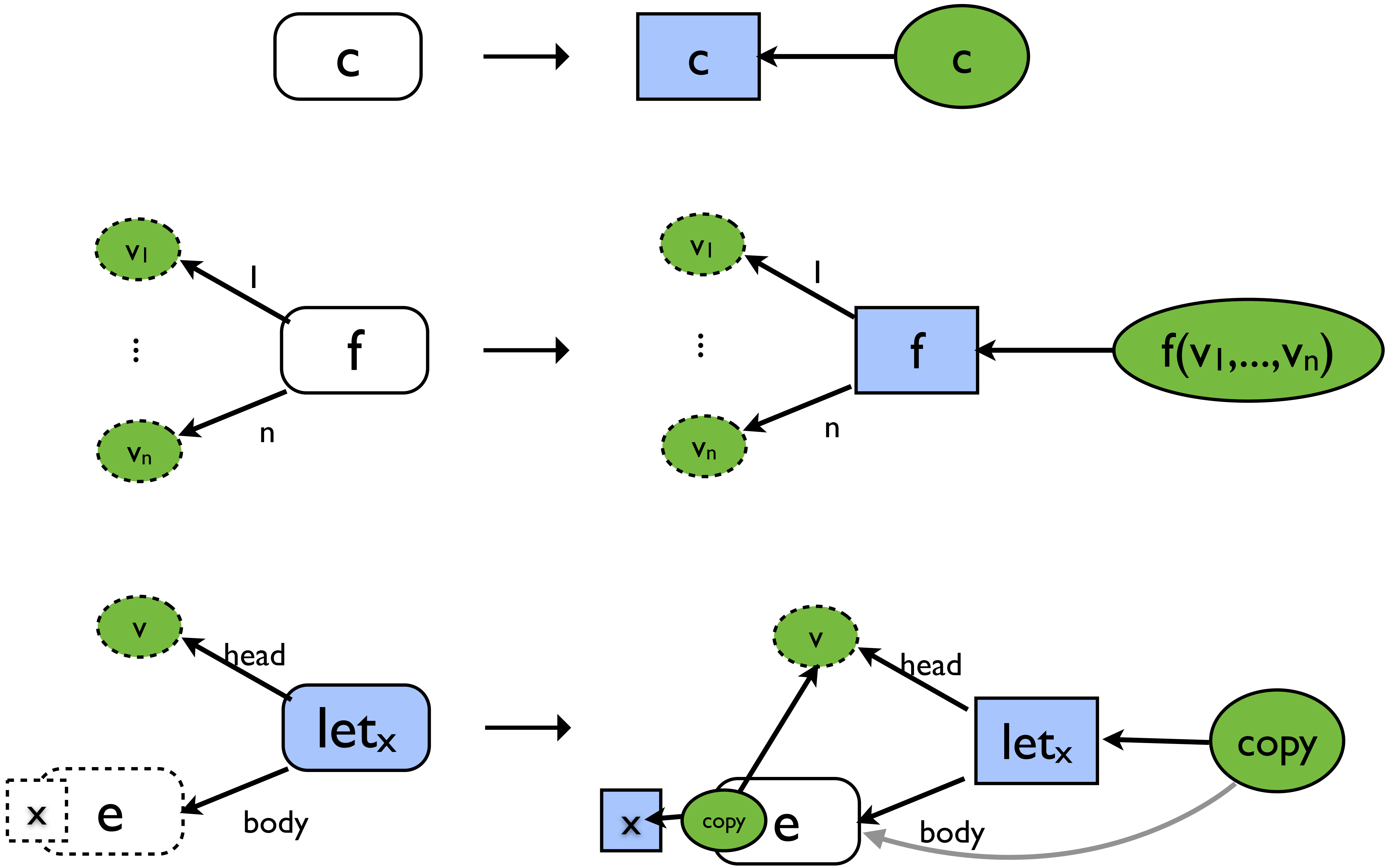


Expression structure

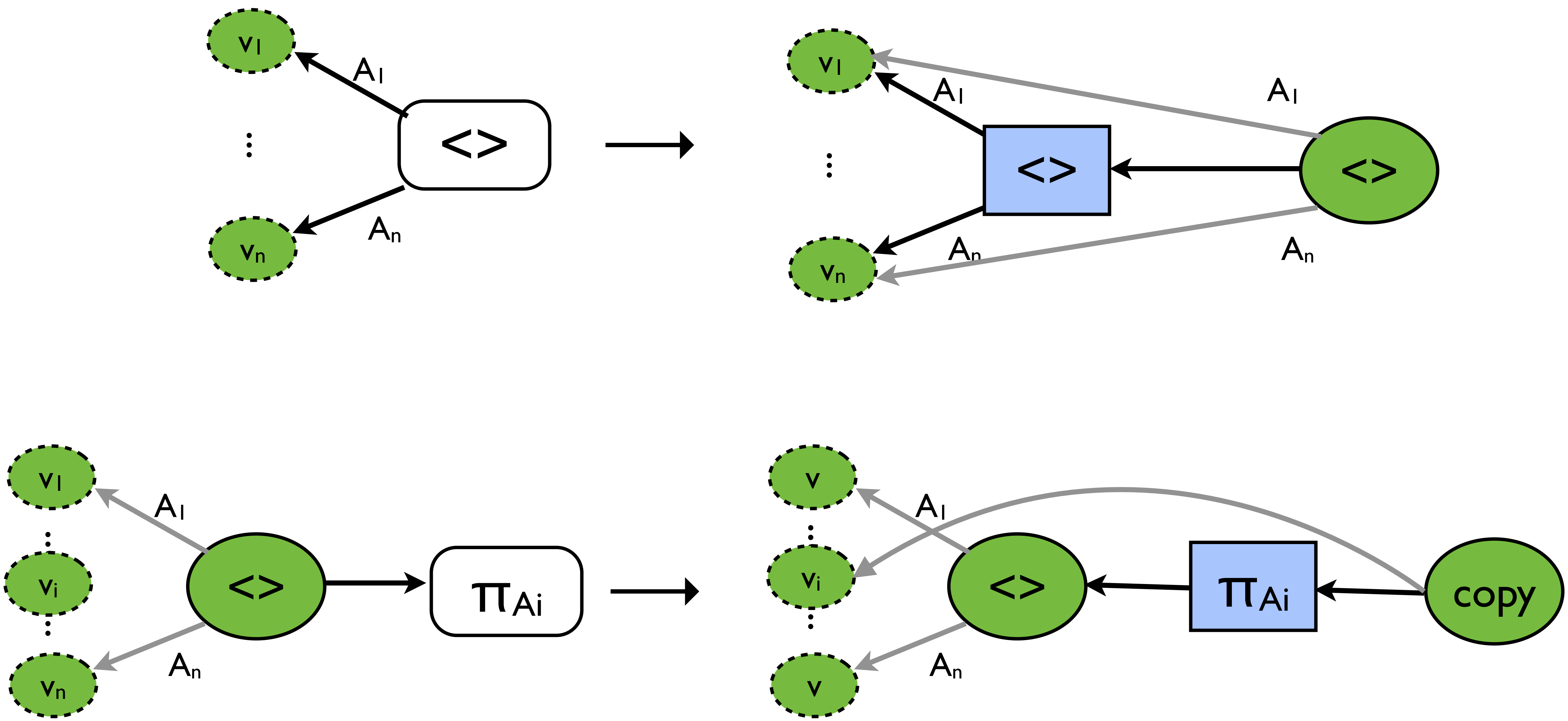


Building provenance graphs

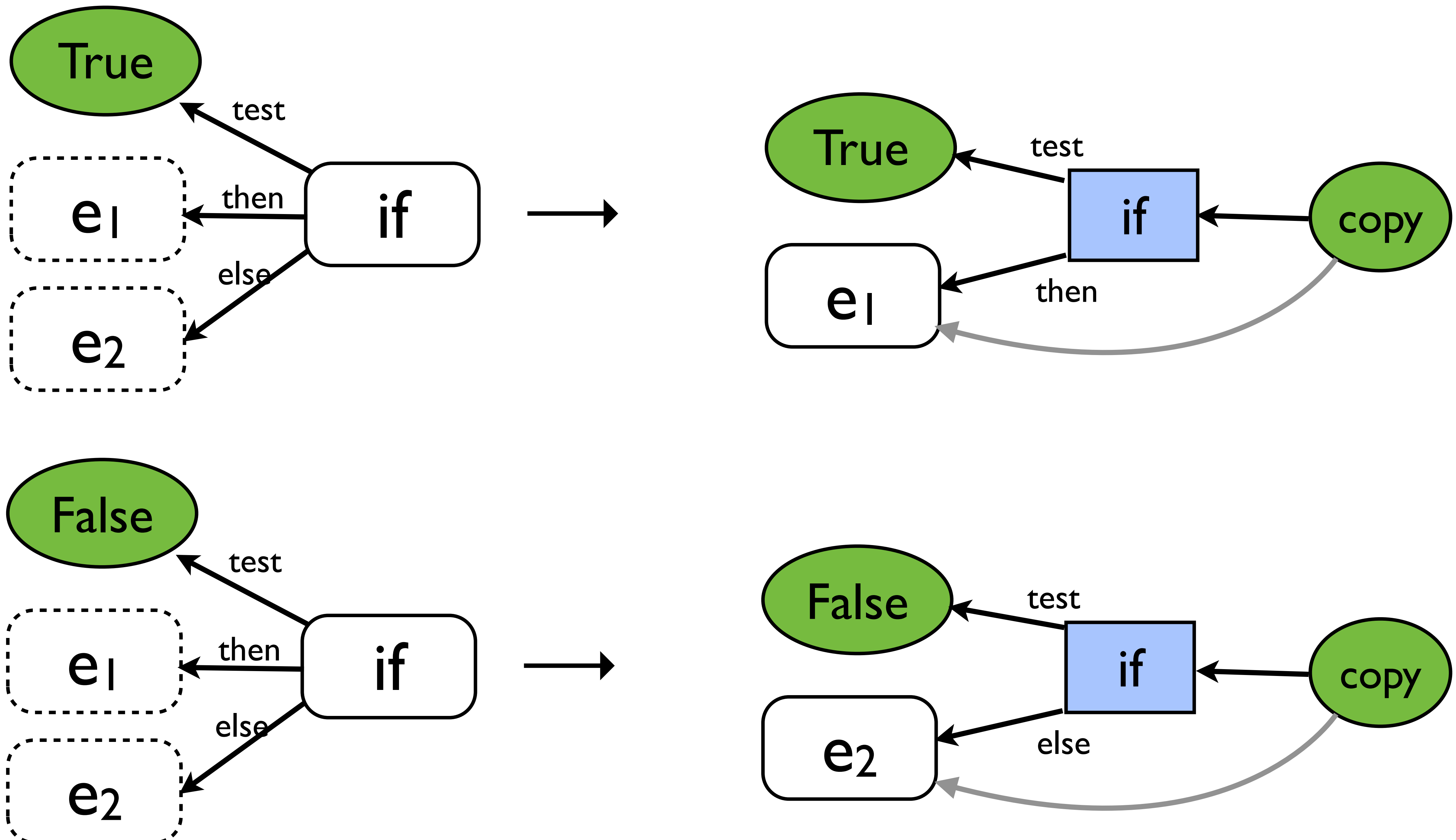
- is complicated
- Here we'll use high-level "graph rewrite rule" formalism
- Mostly because it is nicer to look at than formal version

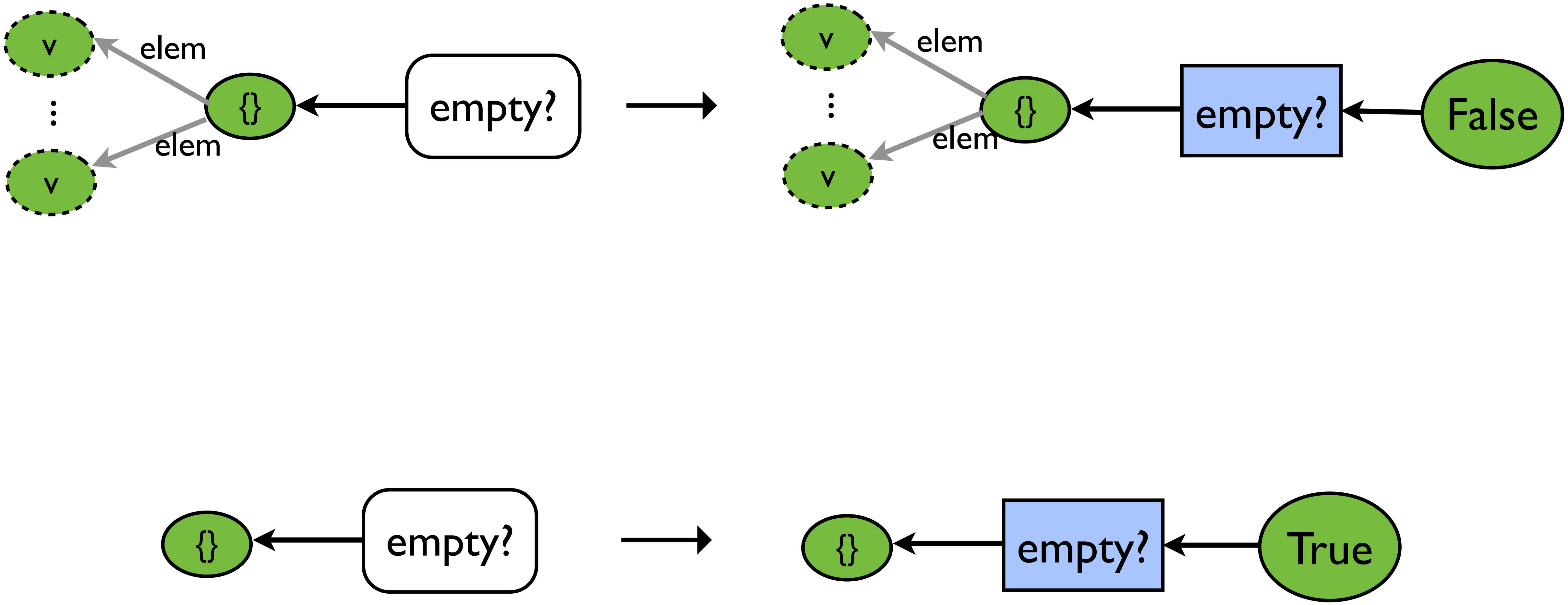


c
c
c
v1
1
f
vn
n
v1
1
f
vn
n
f(v1,...,vn)
v
head
letx
x
e
body
v
head
letx
copy
x
copy
e
body

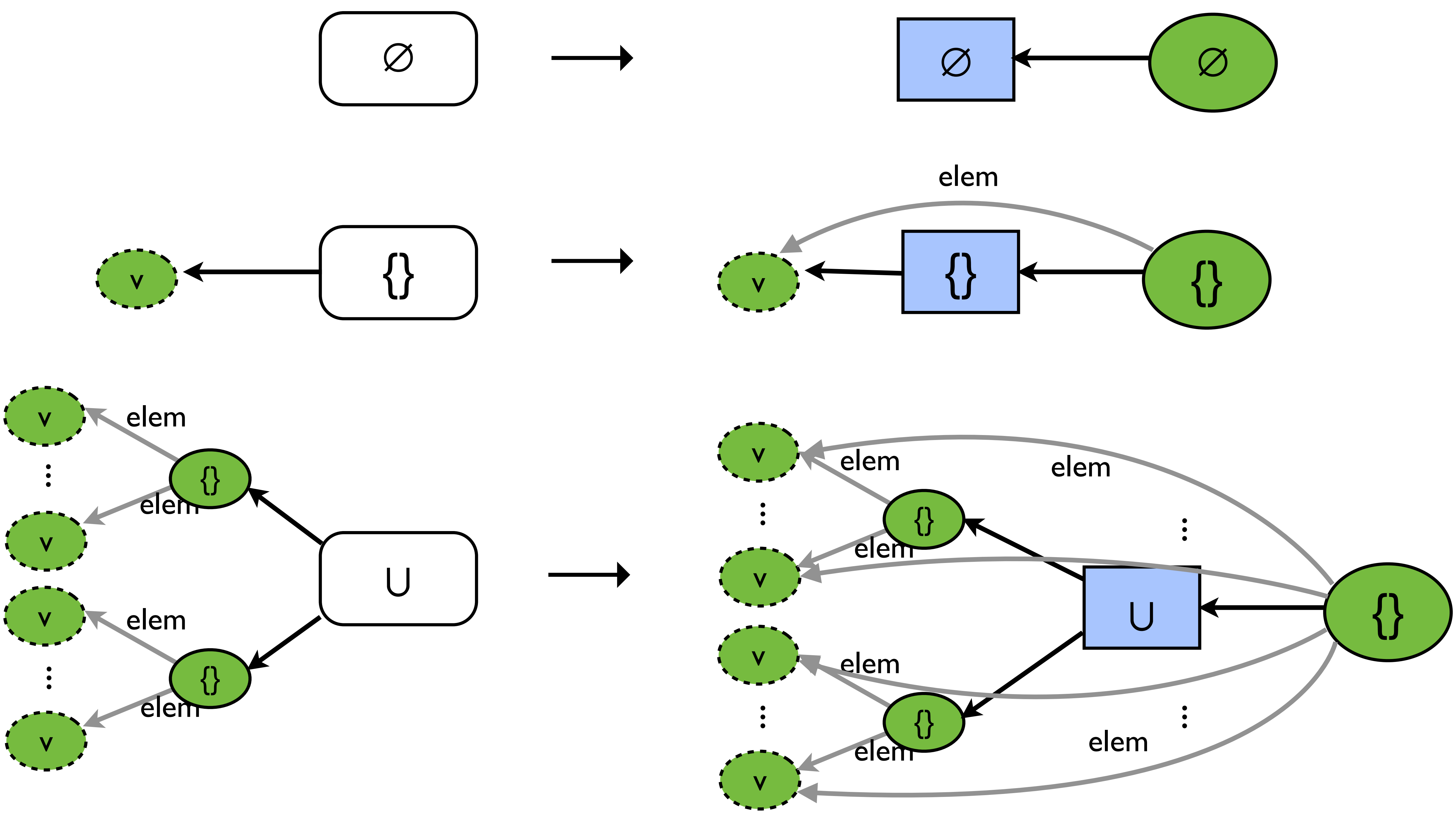


v1
A1
<>
An
vn
v1
A1
<>
A1
<>
An
An
vn
v1
A1
vi
<>
πAi
An
vn
v
A1
vi
<>
πAi
copy
An
v

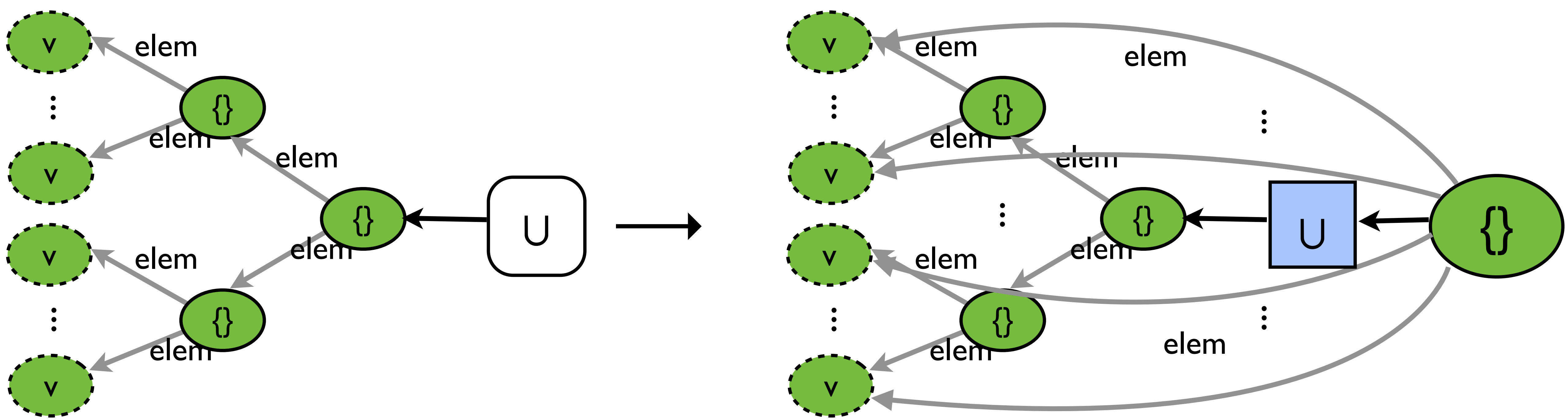

True
test
then
else
if
e_1
e_2
True
test
if
copy
then
e_1
False
test
then
else
if
e_1
e_2
False
test
if
copy
else
e_2

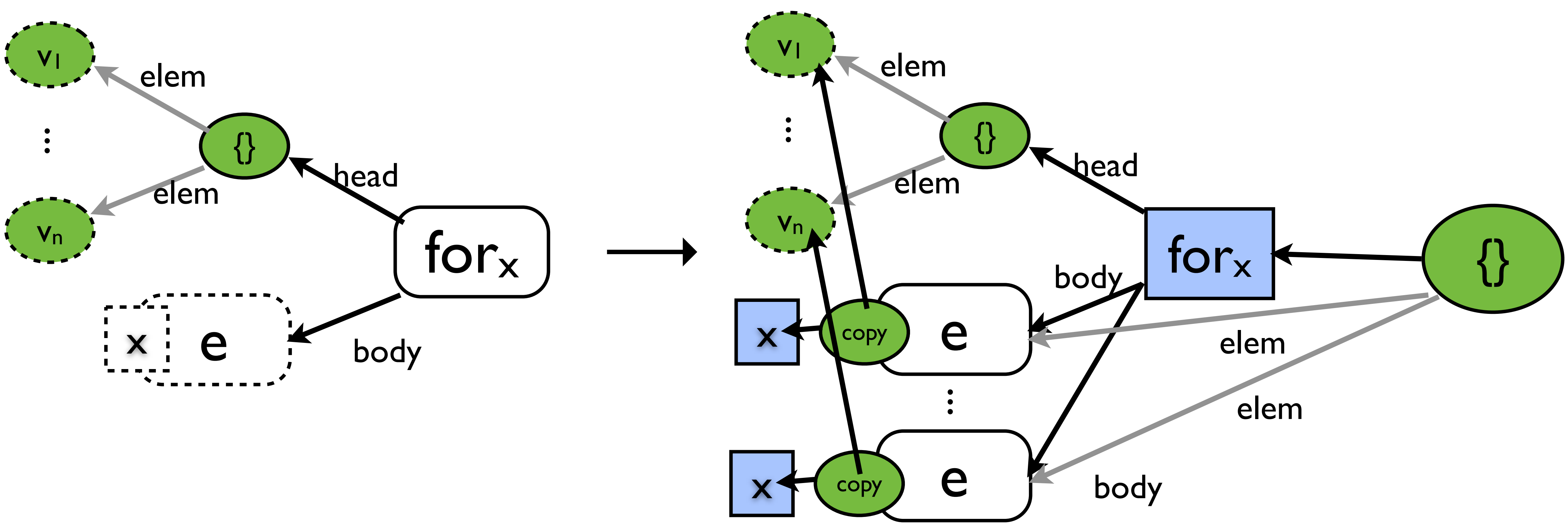


v
elem
{}
empty?
v
elem
v
elem
{}
empty?
False
v
elem
{}
empty?
{}
empty?
True

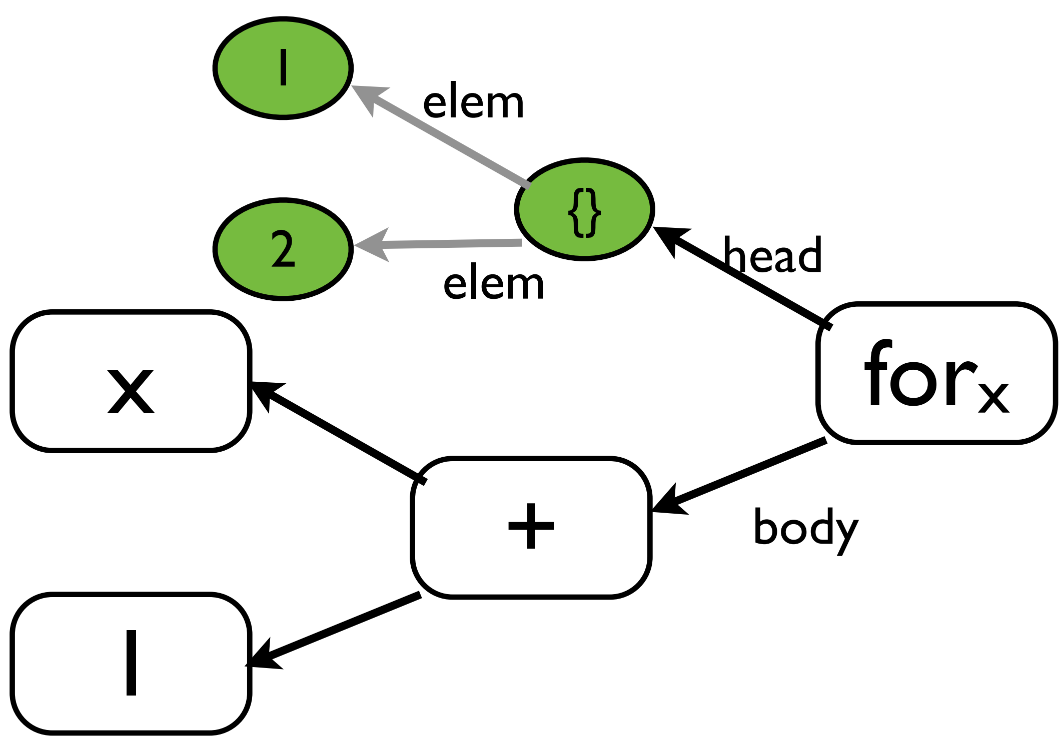

∅
∅
∅
elem
v
{}
v
{}
{}
v
elem
v
{}
elem
v
∪
v
elem
v
{}
elem
v
elem
v
elem
v
elem
v
{}
elem
v
∪
{}
v
elem
v
elem
{}
elem
v
elem

OK, take a deep breath!

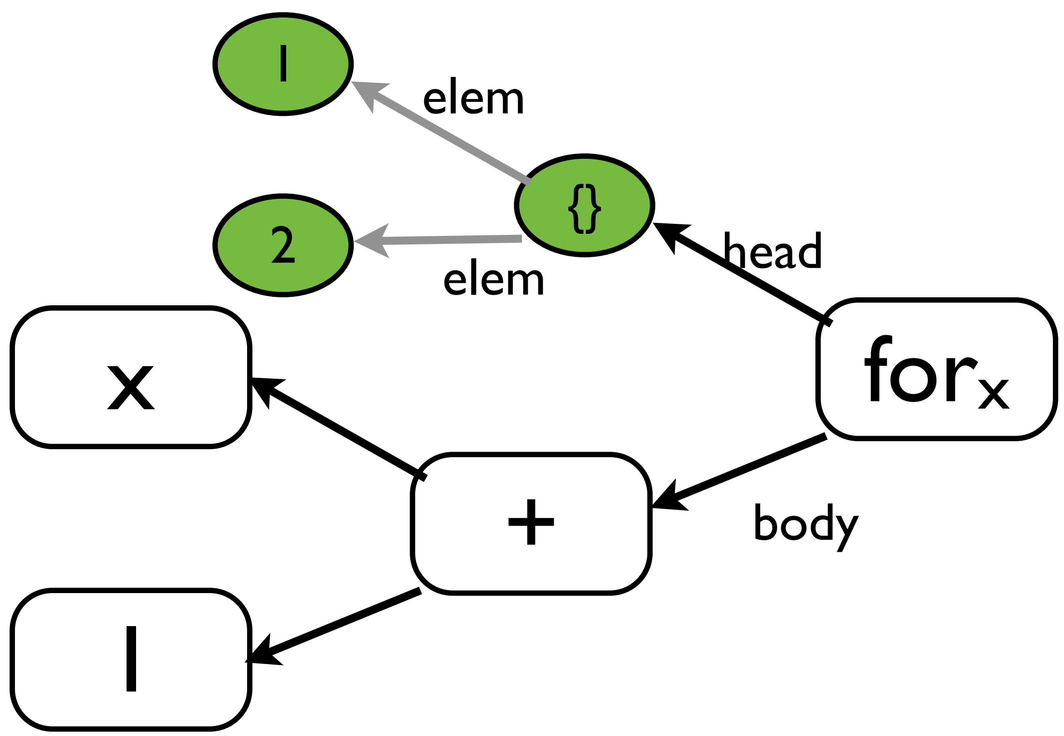

v
elem
{}
U


v1
vn
elem
{}
head
forx
body
x
e
copy

An example



An example



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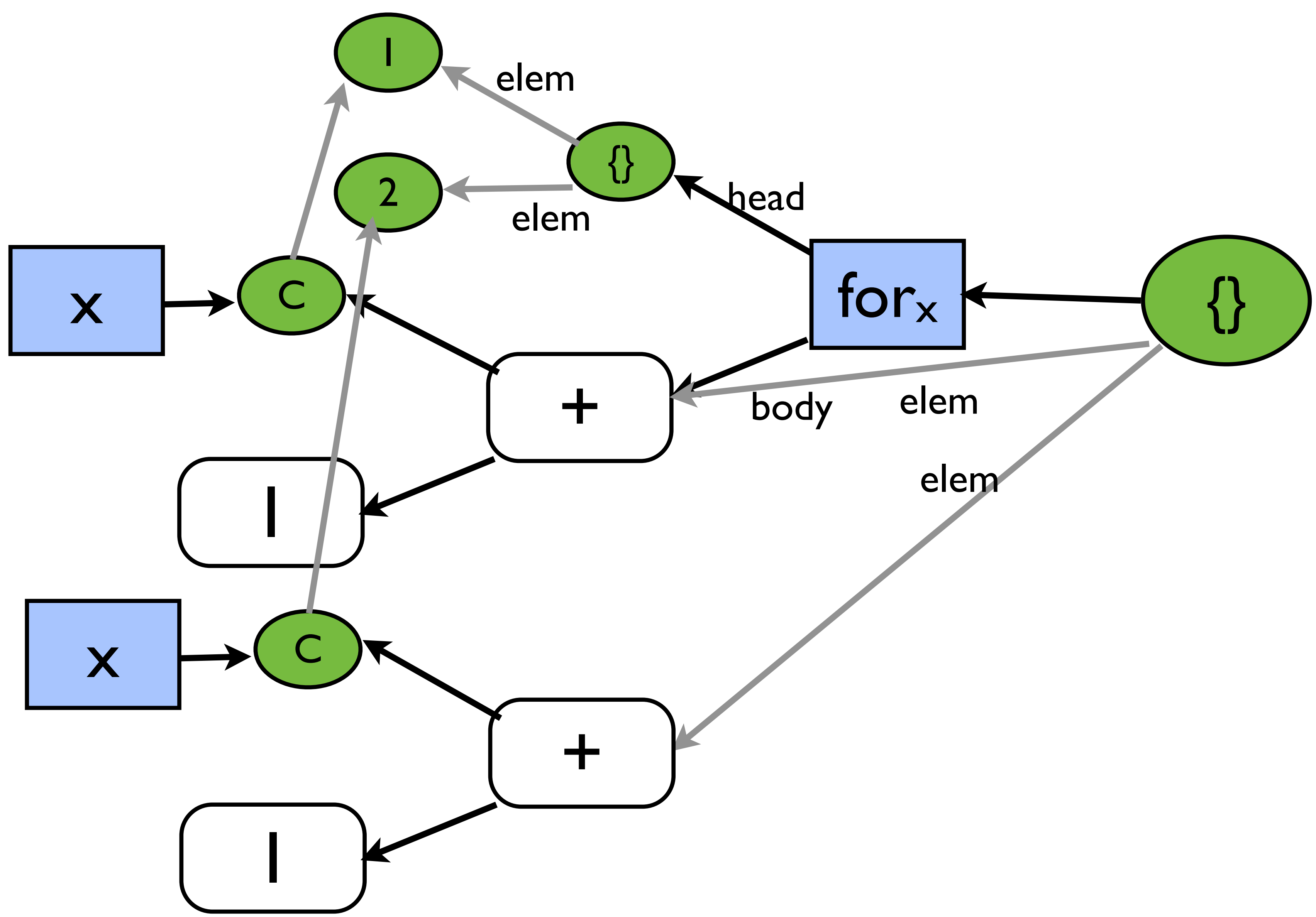
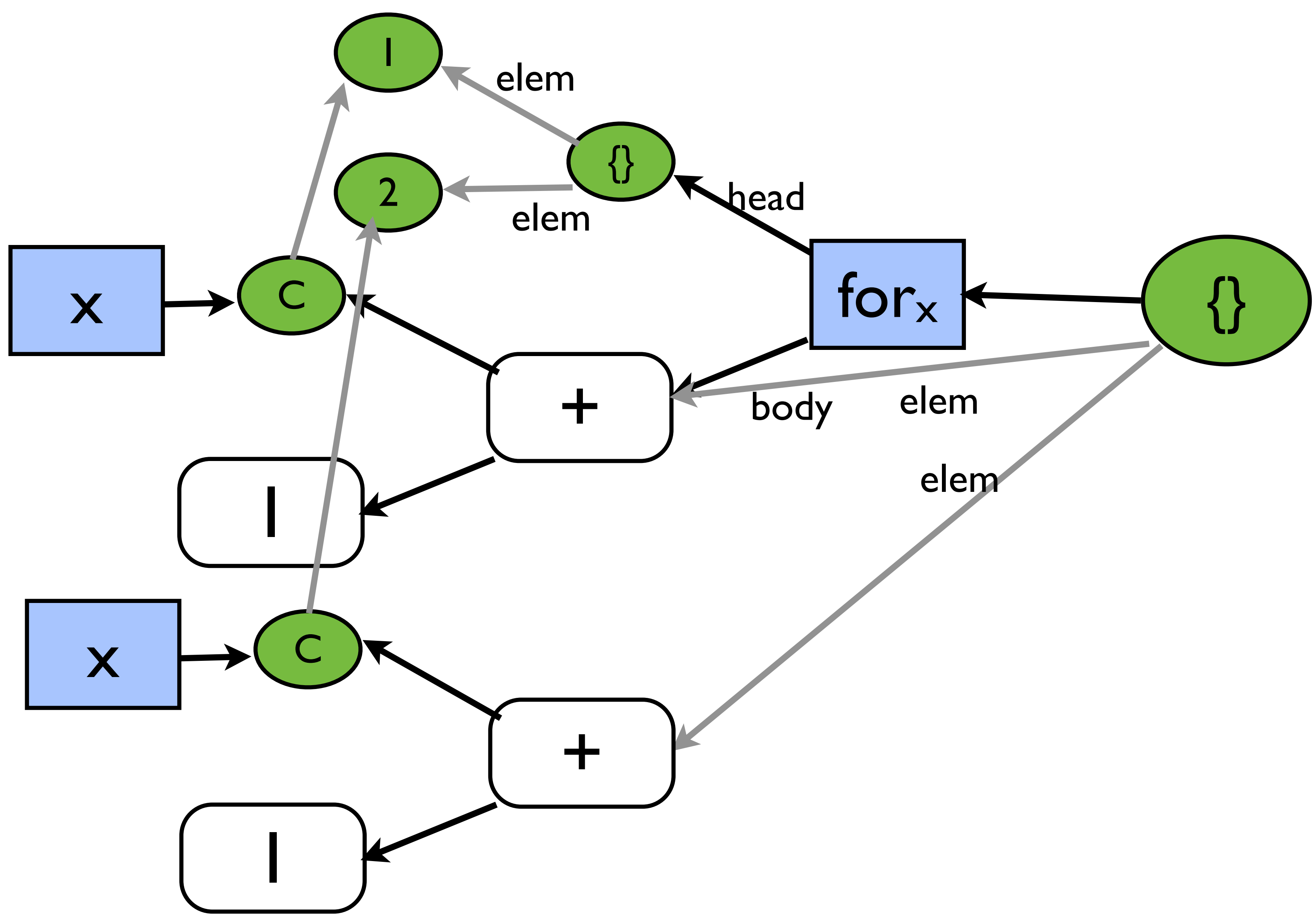
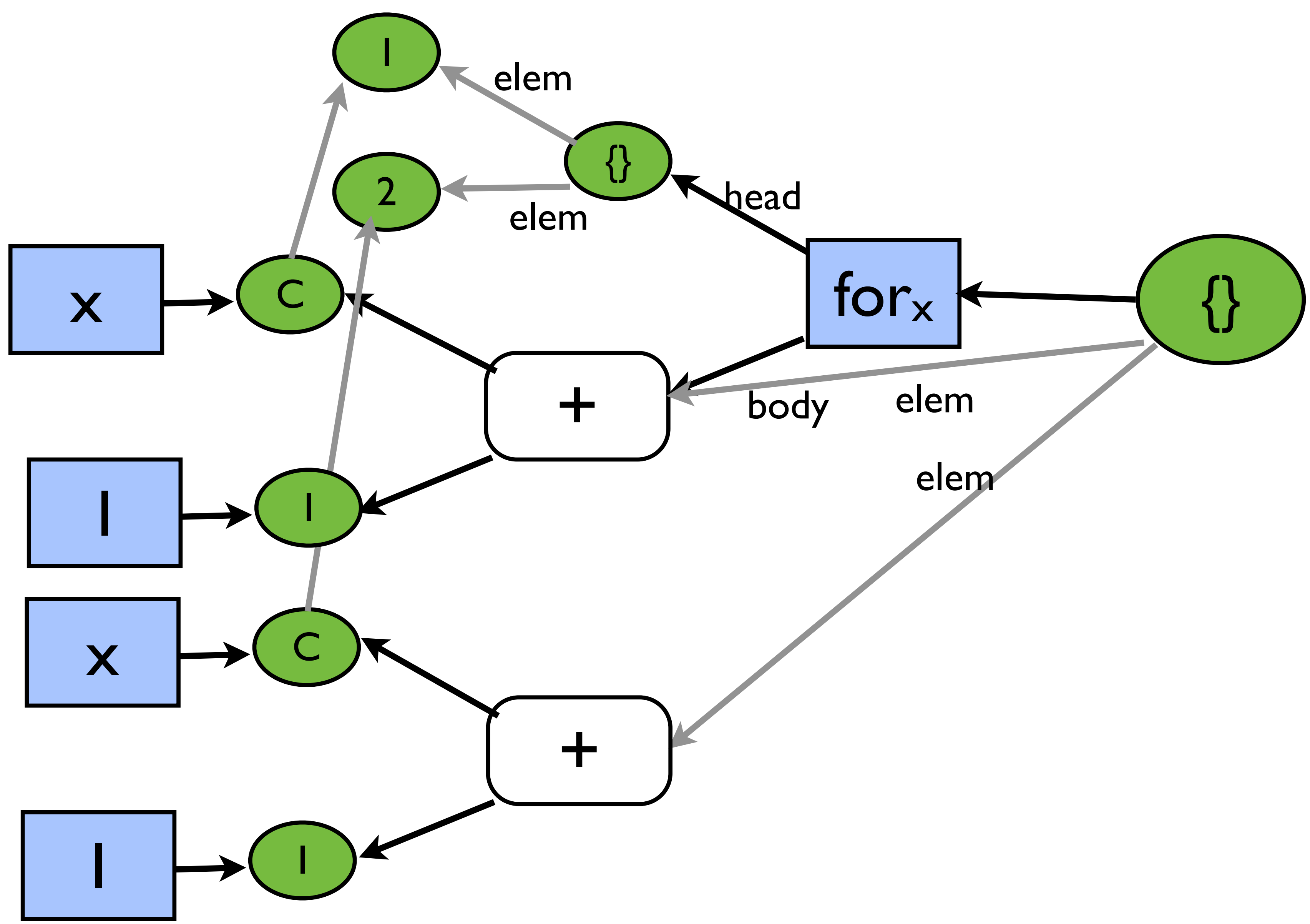


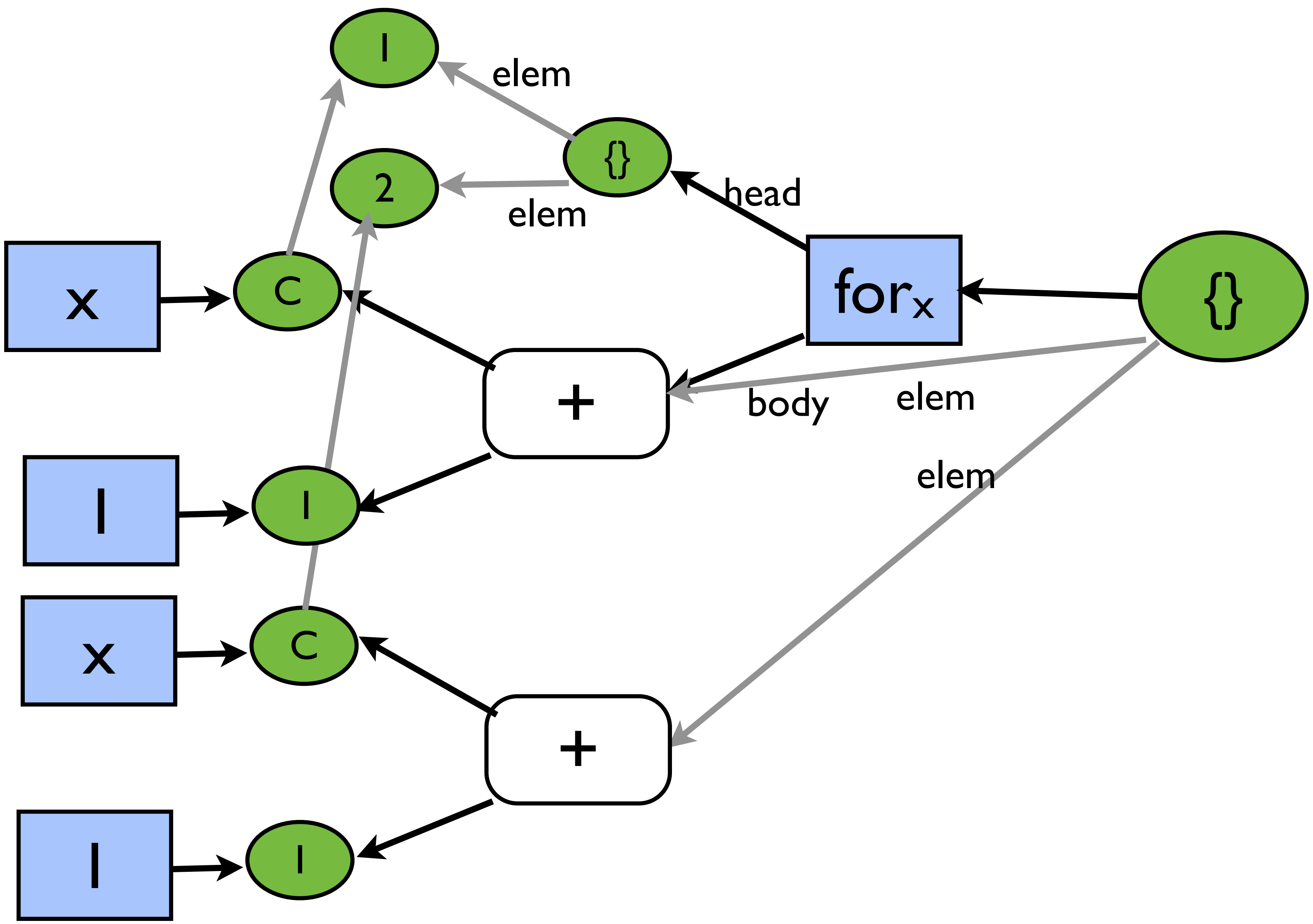
An example



An example



An example



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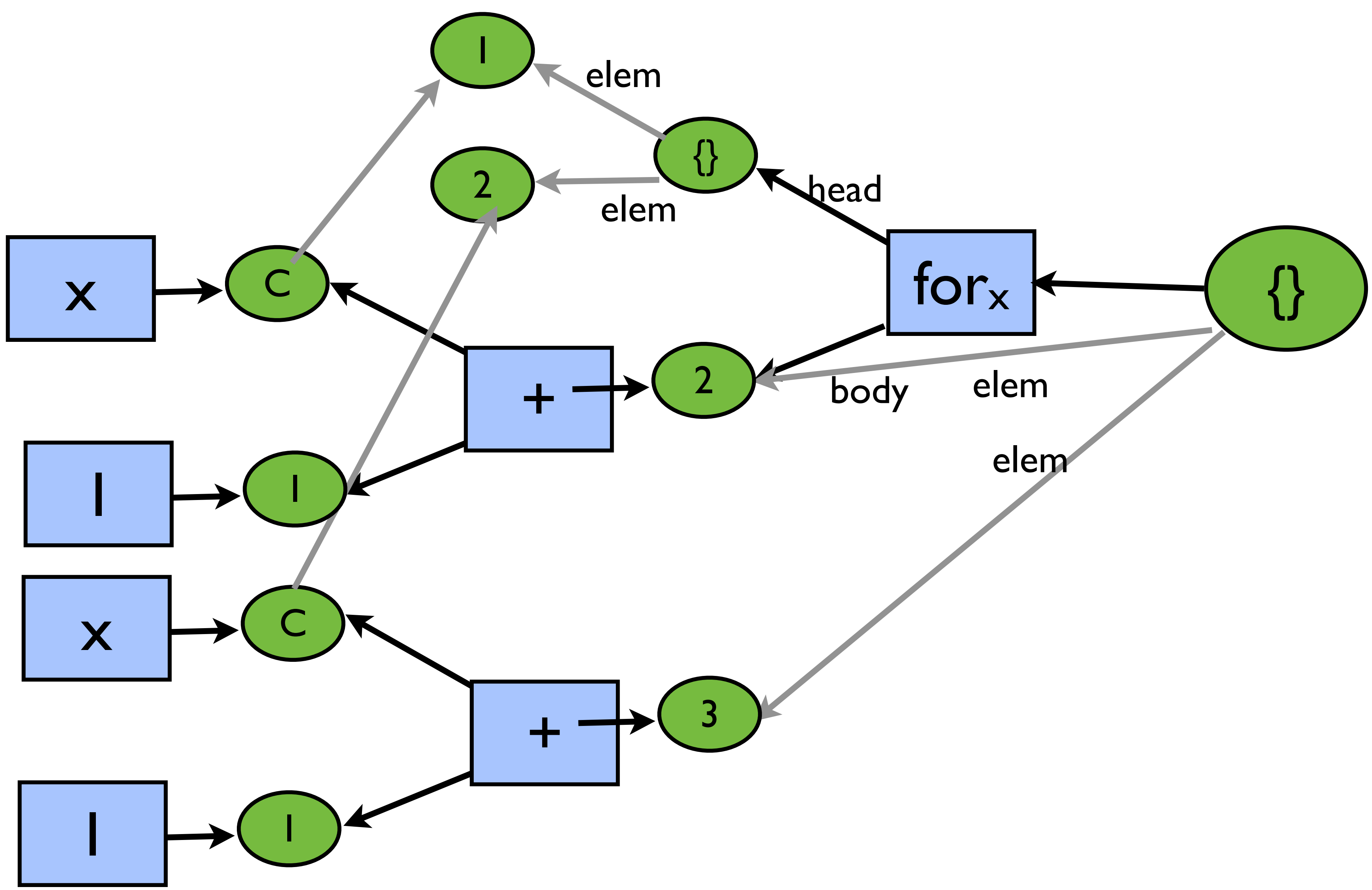
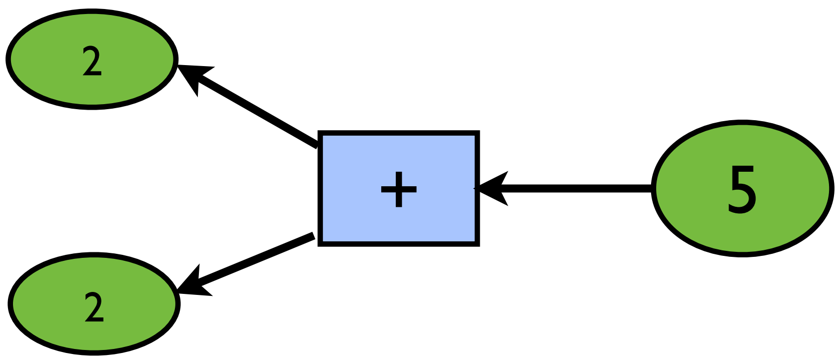


Graphs can "lie" (inconsistency)



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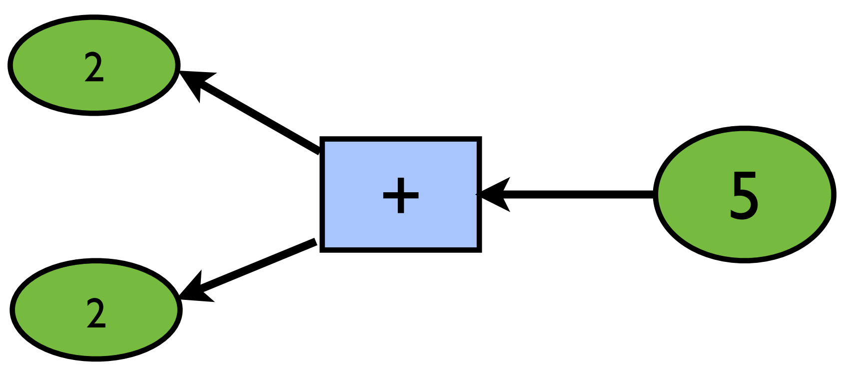

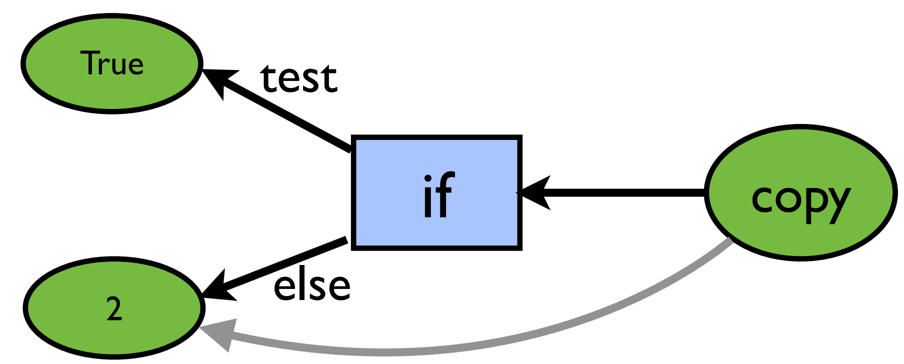

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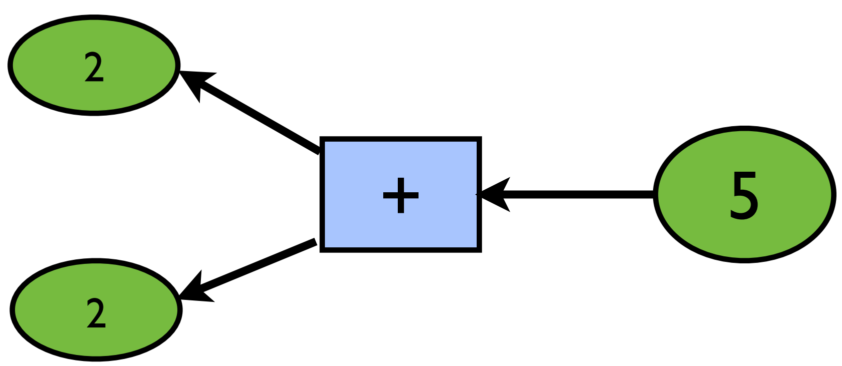

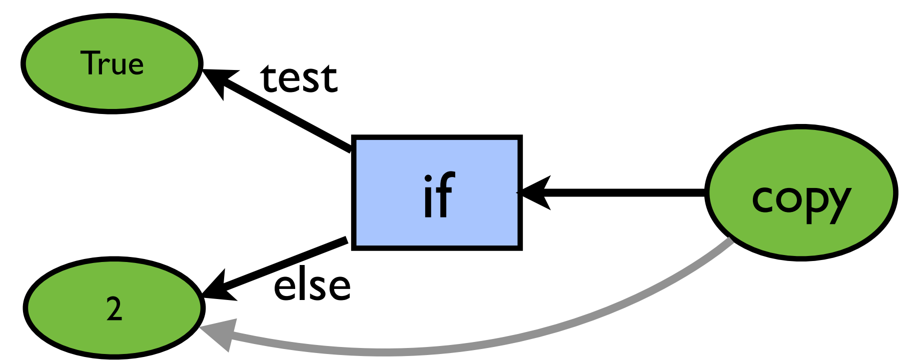

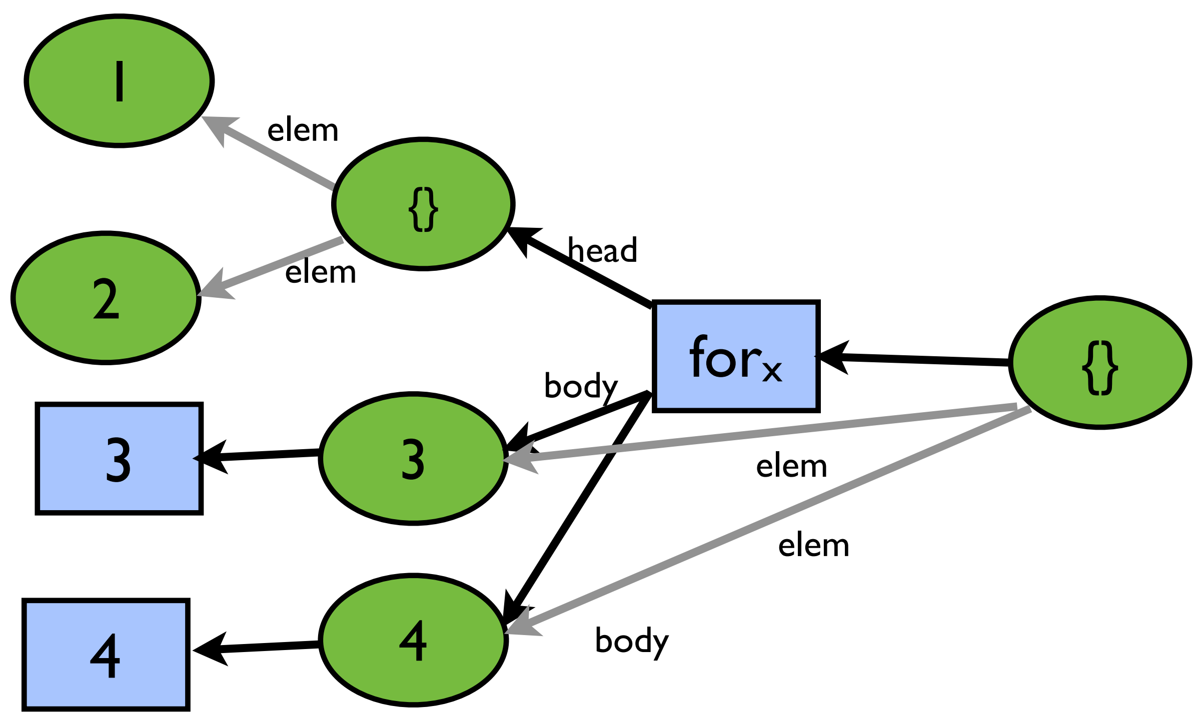

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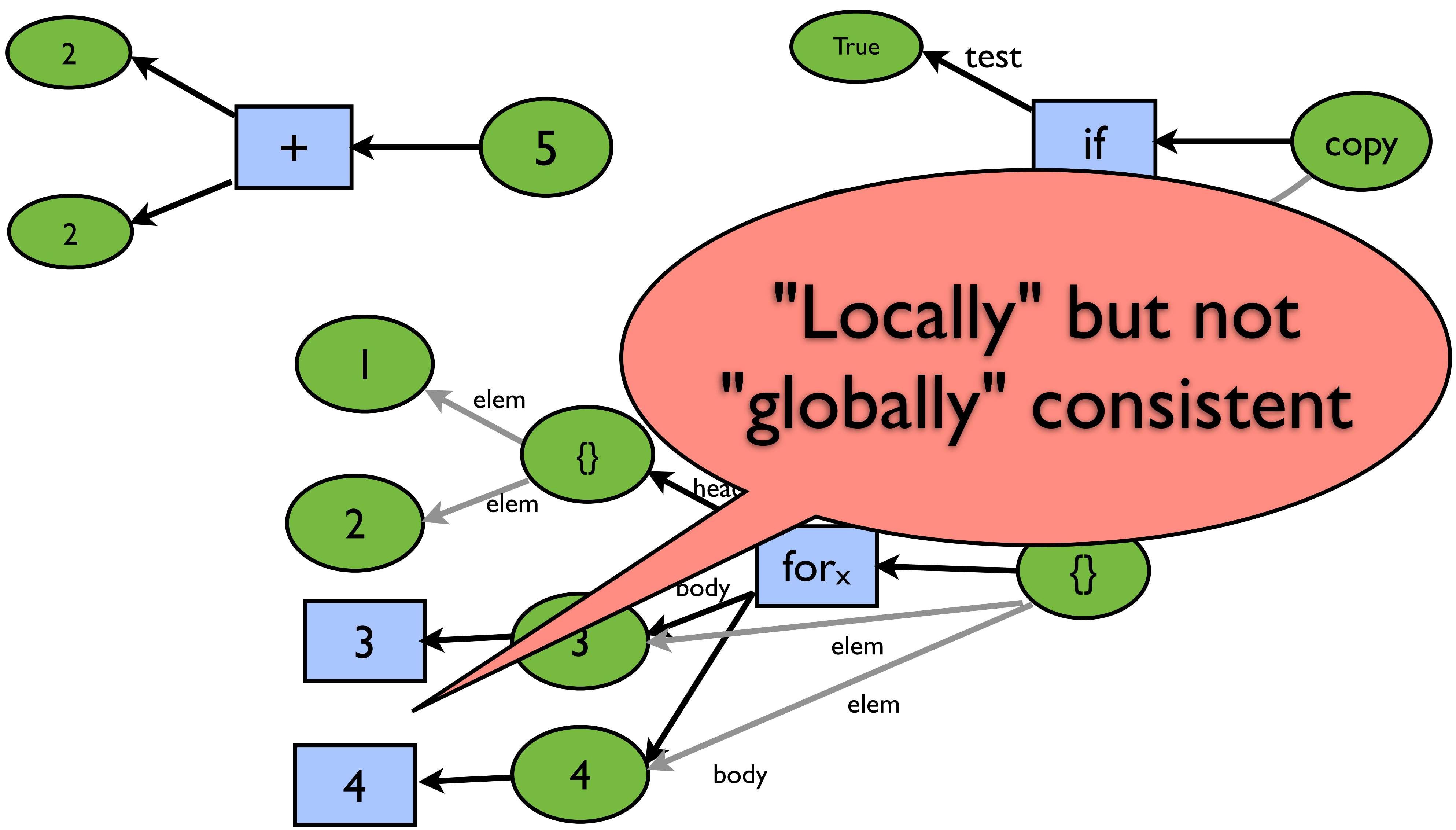
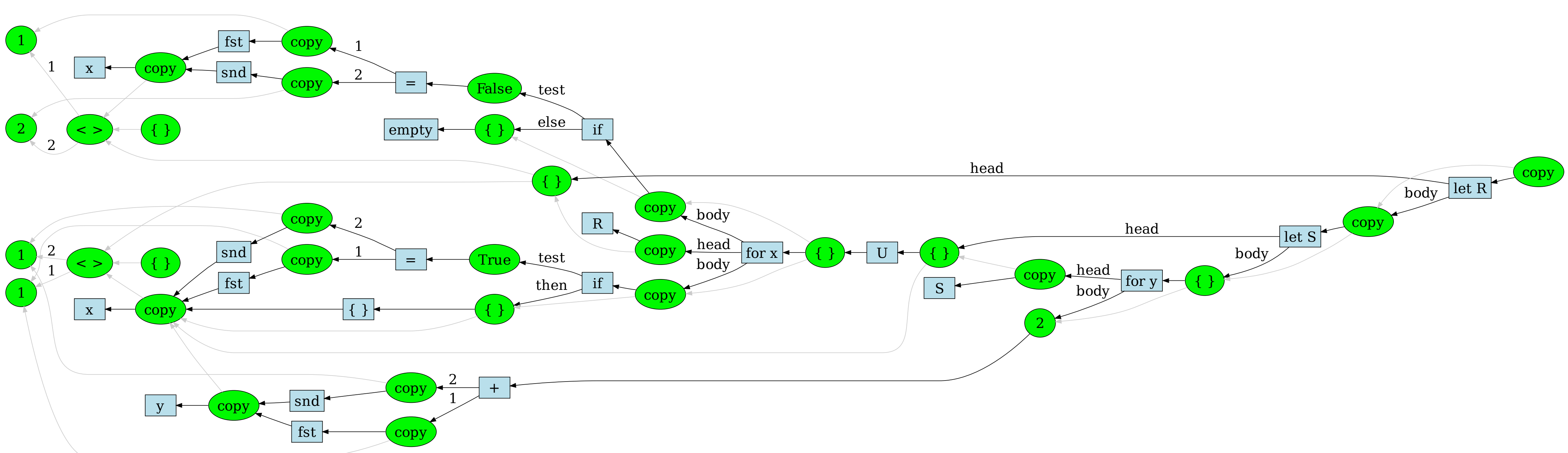


Graph queries

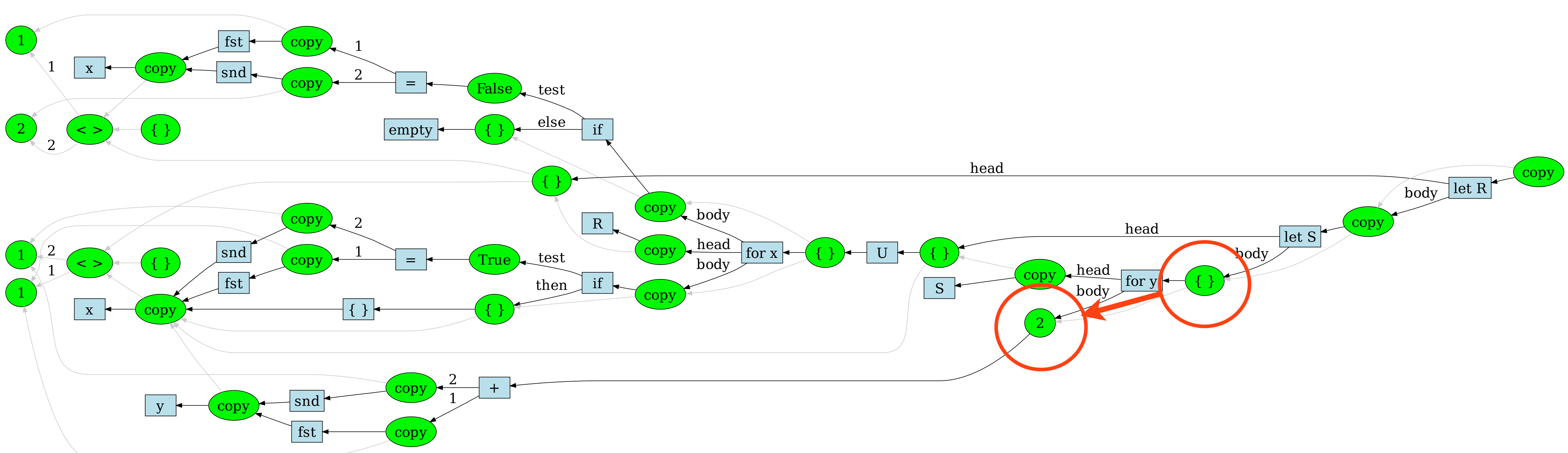
- Many possible approaches
- In paper: some Datalog
  - Maybe overkill, seems fragile
- In code: some "annotation propagation" traversals
  - Seems to handle where, "explanations", "summaries"

Explaining



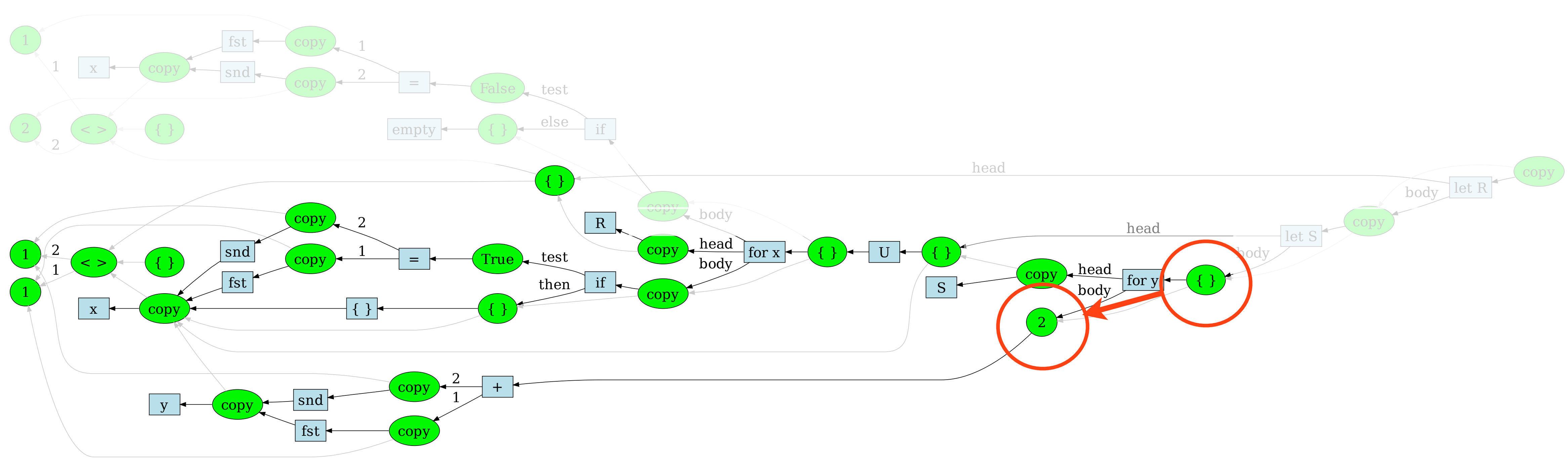
1
x
copy
fst
snd
copy
copy
1
2
=
False
test
2
< >
{ }
empty
{ }
else
if
2
{ }
head
copy
let R
body
copy
R
copy
body
head
for x
body
{ }
U
{ }
let S
head
body
copy
1
< >
{ }
snd
copy
fst
copy
2
1
=
True
test
if
then
copy
1
x
copy
{ }
{ }
S
copy
head
for y
body
{ }
2
copy
2
+
1
y
copy
snd
fst
copy

Explaining



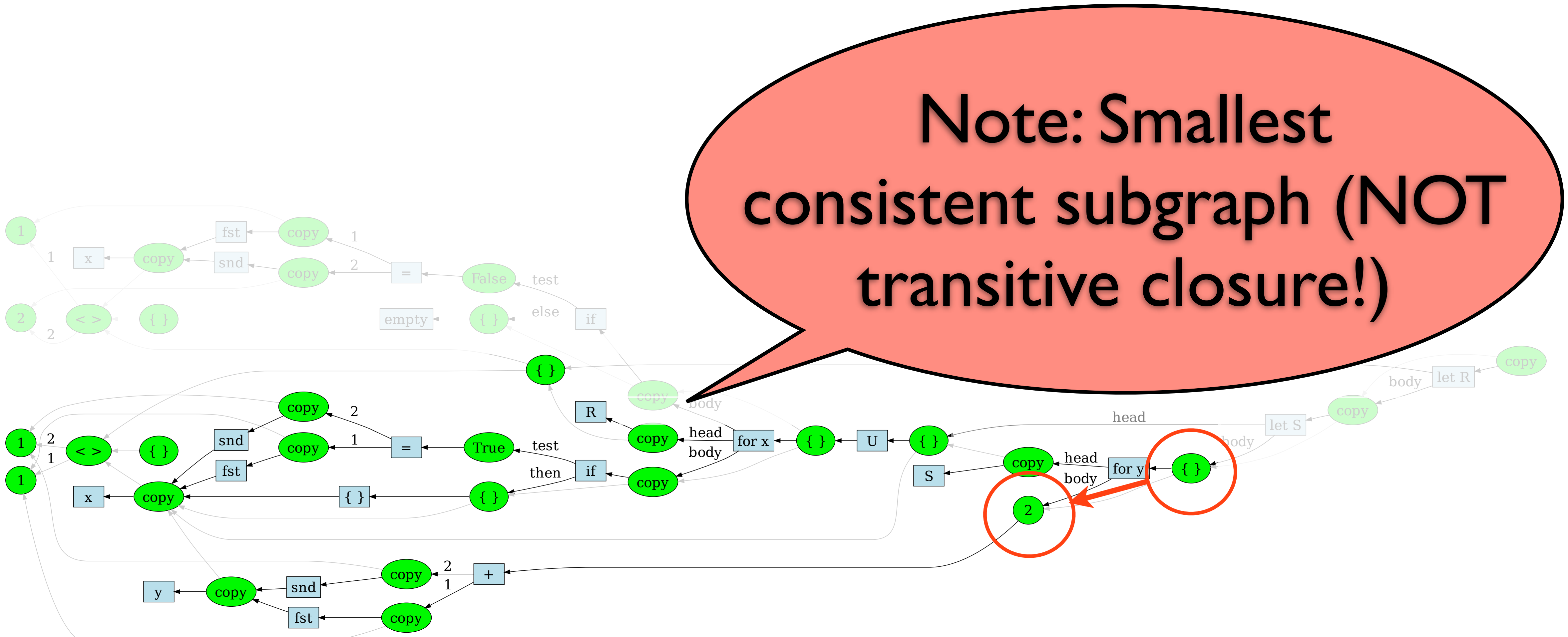
1
fst
copy
x
copy
snd
copy
=
False
test
2
< >
{ }
empty
{ }
else
if
{ }
head
let R
copy
body
copy
R
copy
body
head
for x
{ }
U
{ }
let S
copy
True
if
then
{ }
S
copy
for y
{ }
2
y
snd
fst
+

Explaining

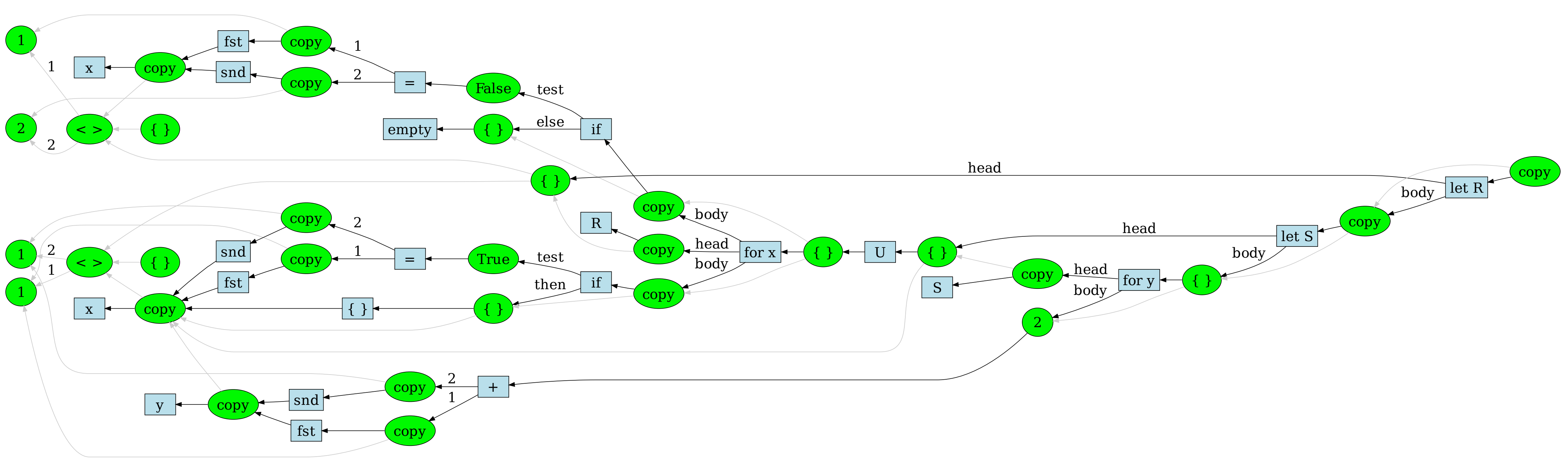


head
copy
body
let R
{ }
head
let S
copy
R
copy
head
for x
body
copy
{ }
U
{ }
copy
head
for y
body
{ }
S
2
True
test
if
then
copy
=
1
2
snd
fst
< >
{ }
1
1
x
copy
{ }
{ }
+
copy
copy
snd
fst
copy
y

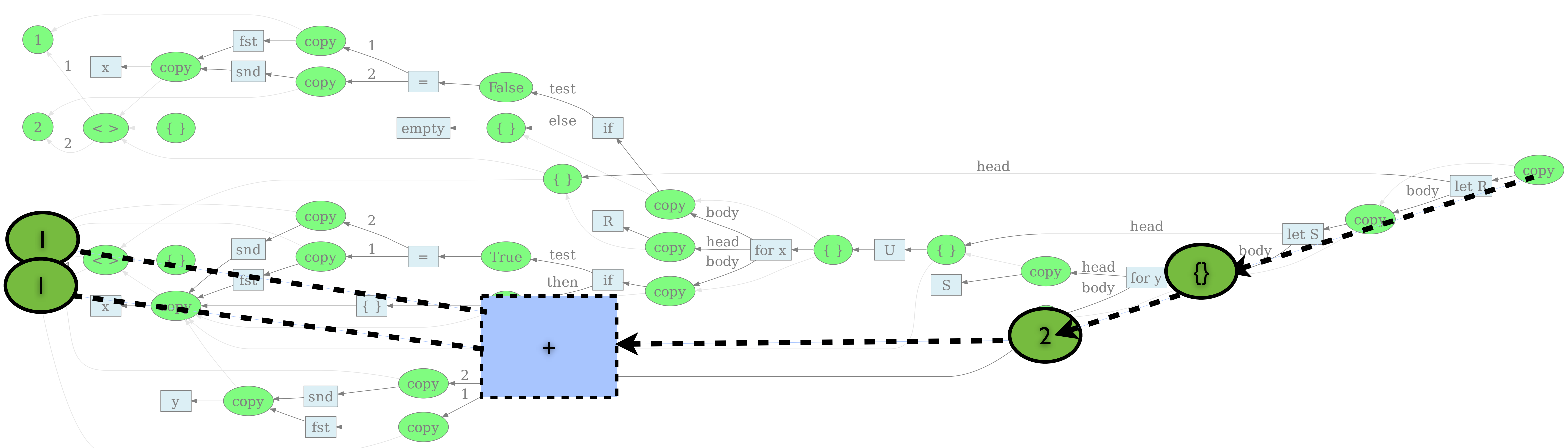
Explaining


Note: Smallest consistent subgraph (NOT transitive closure!)
1
2
< >
{ }
x
copy
snd
fst
=
True
test
then
if
R
head
body
for x
U
S
for y
+
y
empty
else
False
let S
let R

Summarizing

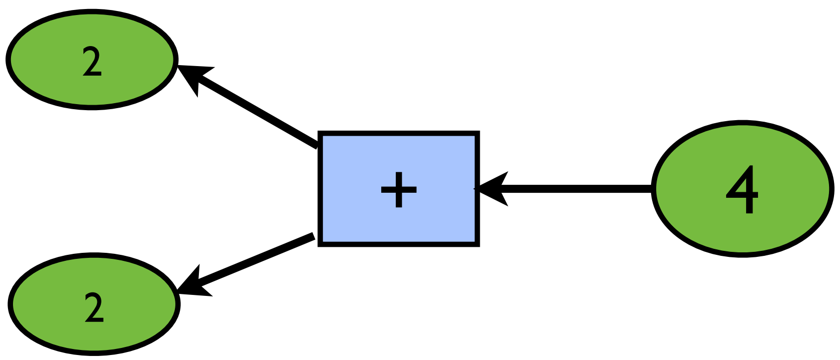


Summarizing



Graphs are partially "replayable"

- If we change a value node, can try to "readjust" to recover consistency



- Formalized in (Acar, Ahmed, Cheney 08)

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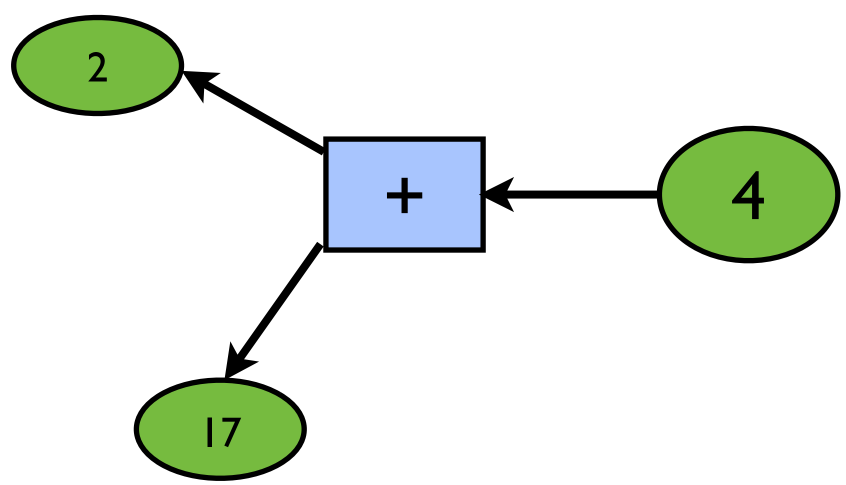

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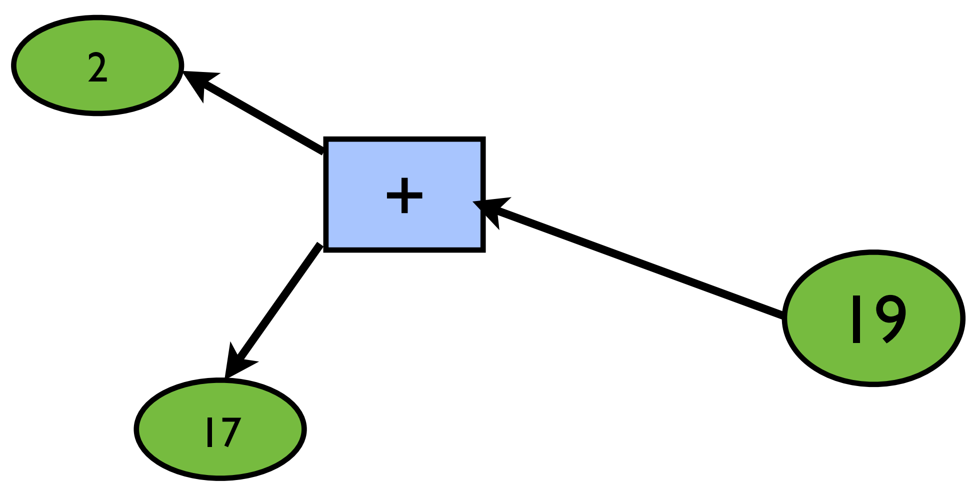

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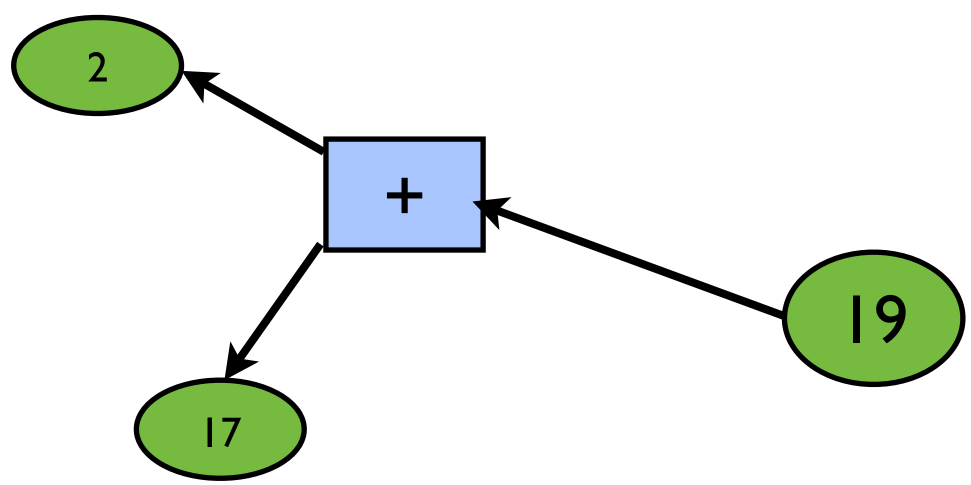

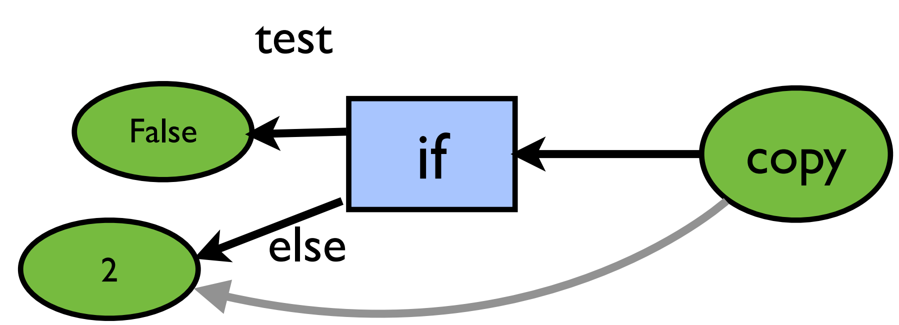

- Formalized in (Acar, Ahmed, Cheney 08)

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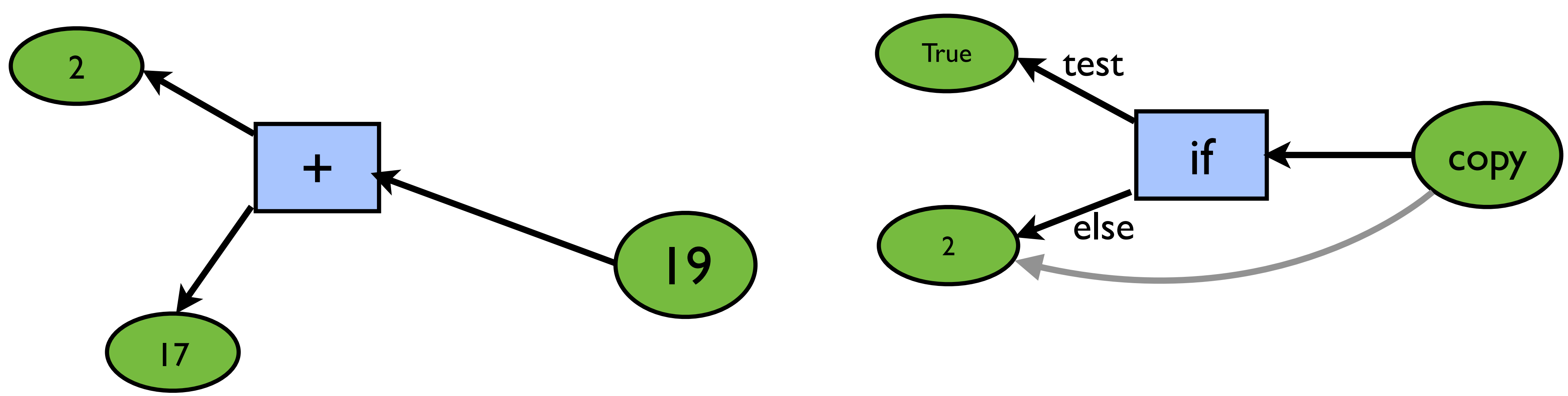

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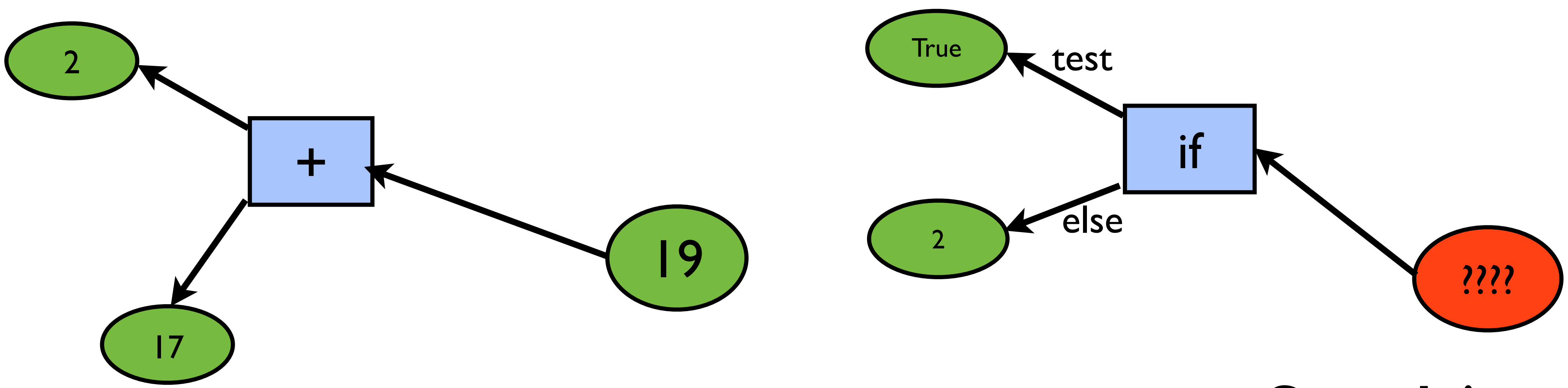

Stuck!

- Formalized in (Acar, Ahmed, Cheney 08)

Implementation in Haskell

- Summarized in paper, full code on request
  - roughly 250 LOC for basic evaluator
  - another 300 for graphviz translation, basic queries, examples
- Point?
  - No claim of efficiency/scalability but easy to understand, experiment
  - Elucidates some tricky details that pictures hide
  - Similar "lightweight modeling" might be valuable for understanding/relating other WF/DB models

Related work

- This work synthesizes/rearranges ideas from several previous works & "folklore"
  - traces (Acar, Ahmed, Cheney 2008)
  - runs (Kwasnikowska, van den Bussche, DILS 2007, IPAW 2008)
  - OPM graphs (Moreau et al. IPAW 2008 etc.)
    - and many workflow systems
- More can be done to relate DB & workflow models

Future work

- This is work in progress
- Next steps:
  - Extending to understand/model other workflow features
  - Better grasp of "real" queries and features needed
  - Implementa(tion|ability)?
  - Optimization?

Conclusions

- DB & WF provenance have much in common
- We develop common graph model
  - with both intuitive & precise presentations
- Still much to do to relate and integrate DB & WF models
  - let alone integrate models at scale in real systems