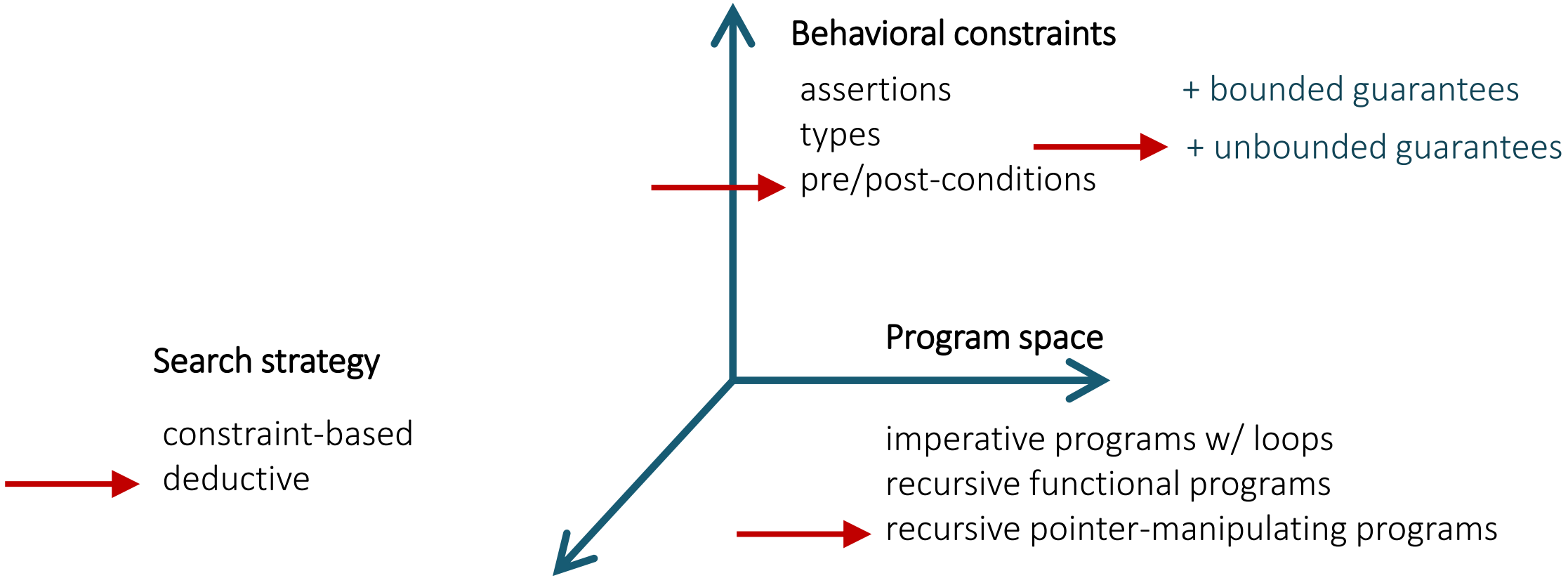
Lecture 14
Separation Logic and Deductive Synthesis

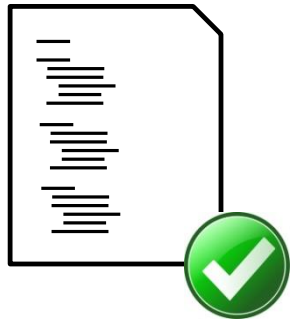
Today


Behavioral constraints
assertions
types
pre/post-conditions
+ bounded guarantees
+ unbounded guarantees
Program space
imperative programs w/ loops
recursive functional programs
recursive pointer-manipulating programs
Search strategy
constraint-based
deductive

Program synthesis

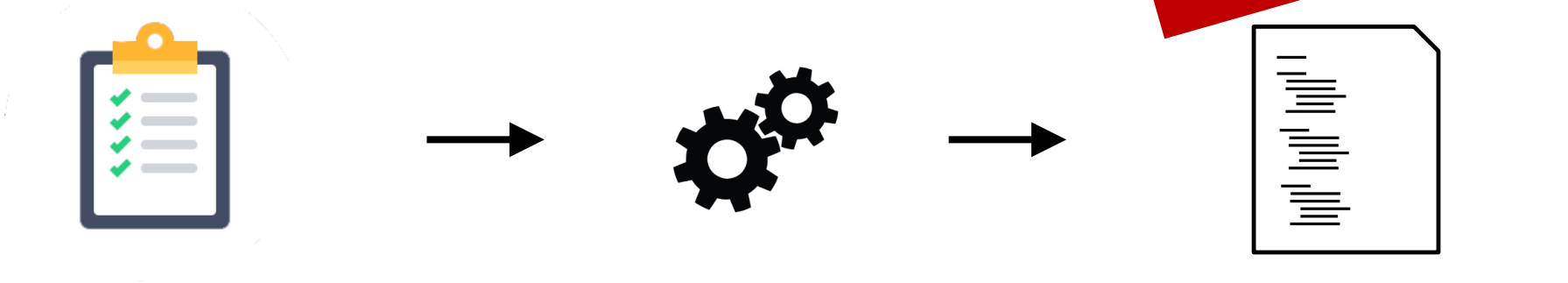
specification

code



Program synthesis

specification



☹ verbose
☹ unstructured
☹ pointers

The trouble with pointers

Can we naively apply Hoare logic to programs with pointers?

$\{* x = 10 \wedge * y = 10\}$

$\Rightarrow$

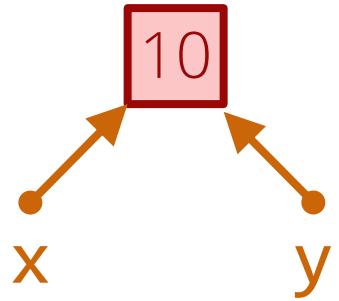
$\{* x + 5 = 15 \wedge * y - 5 = 5\}$

```
*x = *x + 5;
```

$\{* x = 15 \wedge * y - 5 = 5\}$

```
*y = *y - 5;
```

$\{* x = 15 \wedge * y = 5\}$



SuSLik

Synthesis Using Separation Logik

The SuSLik approach

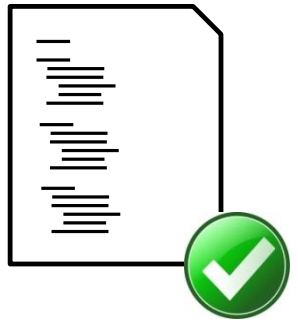
separation logic

☺ reasoning about pointers & aliasing

deductive synthesis

☺ uses specs to guide synthesis

code



Outline

example: swap

a taste of SuSLik

separation logic

specifying pointer-manipulating programs

deductive synthesis

from SL specifications to programs

Outline

example: swap

separation logic

deductive synthesis

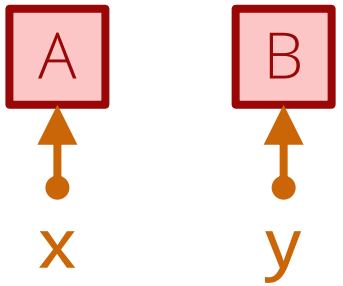
Example: swap

Swap values of two *distinct* pointers

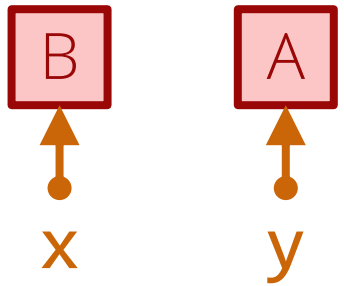
```
void swap(loc x, loc y)
```

Example: swap

start state:



end state:



in separation logic:

$\{ x \mapsto A * y \mapsto B \}$ precondition

separately

```
void swap(loc x, loc y)
```

$\{ x \mapsto B * y \mapsto A \}$ postcondition

ghost variables

Demo: swap

Swap values of two *distinct* pointers

```
void swap(loc x, loc y)
```

$$\{\ x \mapsto A\ *\ y \mapsto B\ \}$$

??

$$\{\ x \mapsto B\ *\ y \mapsto A\ \}$$

```
let a1 = *x;
```

$\{ x \mapsto a1 * y \mapsto B \}$

??

$\{ x \mapsto B * y \mapsto a1 \}$

```
let a1 = *x;
let b1 = *y;
```

$\{ x \mapsto a1 * y \mapsto b1 \}$

??

$\{ x \mapsto b1 * y \mapsto a1 \}$

```
let a1 = *x;
let b1 = *y;
*x = b1;
```

$\{ x \mapsto b1 * y \mapsto b1 \}$

??

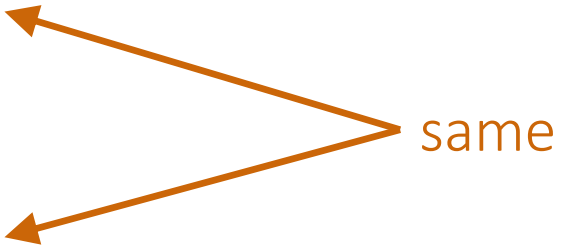
$\{ x \mapsto b1 * y \mapsto a1 \}$

```
let a1 = *x;
let b1 = *y;
*x = b1;
*y = a1;
```

$\{ x \mapsto b1 * y \mapsto a1 \}$

??

$\{ x \mapsto b1 * y \mapsto a1 \}$



```
let a1 = *x;
let b1 = *y;
*x = b1;
*y = a1;
```

```
void swap(loc x, loc y) {
        let a1 = *x;
        let b1 = *y;
        *x = b1;
        *y = a1;
}
```

Outline

example: swap

separation logic

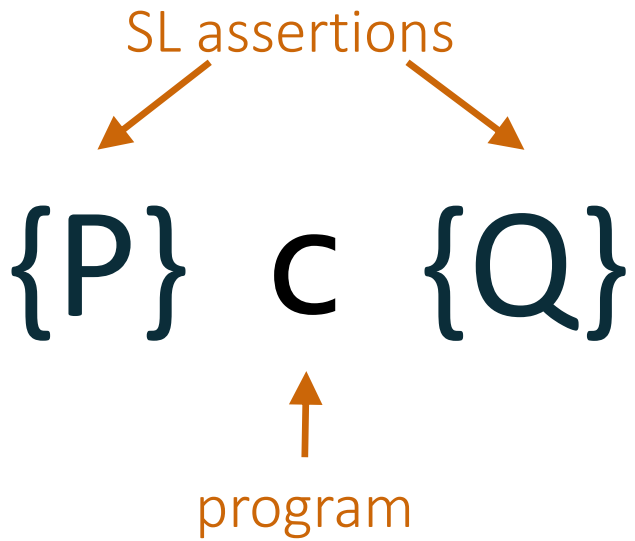
deductive synthesis

Separation logic (SL)

Hoare logic

"about the heap"

Separation logic (SL)



starting in a state that satisfies P
program c will execute without memory errors,
and upon its termination the state will satisfy Q

Outline

example: swap

separation logic

2.1. programs
2.2. assertions
2.3. specifying data transformations

deductive synthesis

Separation logic (SL)

$$\{P\}\ c\ \{Q\}$$

program

Programs

do nothing **skip**

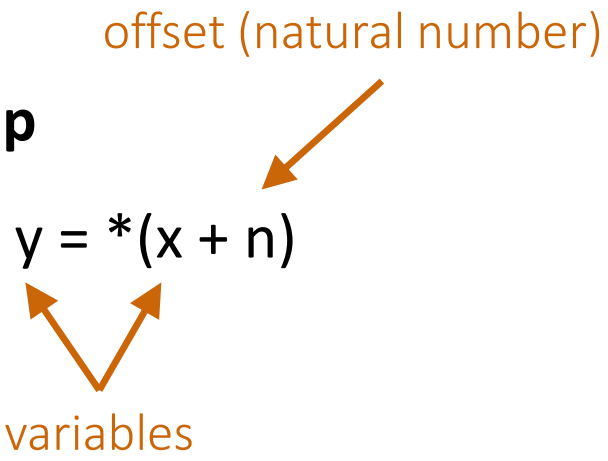
Programs

do nothing

skip

read from heap

let y = *(x + n)



Programs

do nothing	**skip**
read from heap	**let** y = *(x + n)
write to heap	*(x + n) = e ← expression (arithmetic, boolean)

Programs

do nothing	**skip**
read from heap	**let** y = *(x + n)
write to heap	*(x + n) = e
allocate block	**let** y = **malloc**(n)

Programs

do nothing	**skip**
read from heap	**let** y = *(x + n)
write to heap	*(x + n) = e
allocate block	**let** y = **malloc**(n)
free block	**free**(x)

Programs

do nothing	**skip**
read from heap	**let** y = *(x + n)
write to heap	*(x + n) = e
allocate block	**let** y = **malloc**(n)
free block	**free**(x)
procedure call	$p(e_1, \ldots, e_n)$

Programs

do nothing	**skip**
read from heap	**let** y = *(x + n)
write to heap	*(x + n) = e
allocate block	**let** y = **malloc**(n)
free block	**free**(x)
procedure call	$p(e_1, \ldots, e_n)$
~~assignment~~	only heap is mutable, not stack variables!

Programs

do nothing	**skip**
read from heap	**let** y = *(x + n)
write to heap	*(x + n) = e
allocate block	**let** y = **malloc**(n)
free block	**free**(x)
procedure call	$p(e_1, \ldots, e_n)$
sequential composition	$c_1 ; c_2$
conditional	**if** (e) $\{c_1\}$ else $\{c_2\}$

Outline

example: swap

separation logic

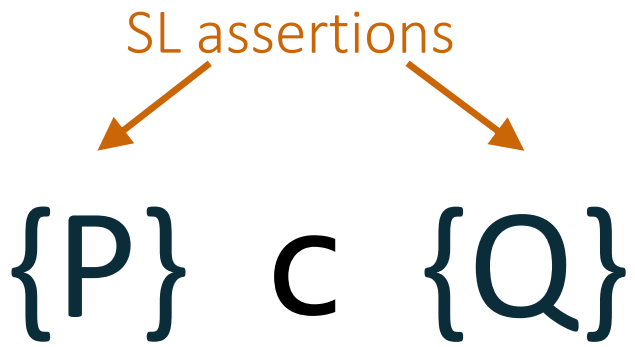
2.1. programs

2.2. assertions

2.3. specifying data transformations

deductive synthesis

Separation logic (SL)



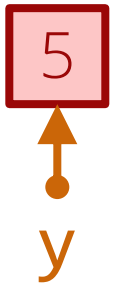
SL assertions

empty heap { emp }

SL assertions

empty heap { emp }

singleton heap { y ↦ 5 }



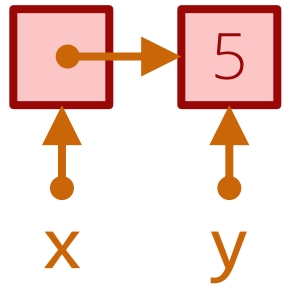
SL assertions

empty heap { emp }

singleton heap { y ↦ 5 }

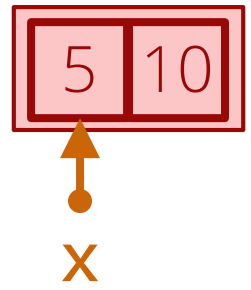
separating conjunction { x ↦ y * y ↦ 5 }

heaplets



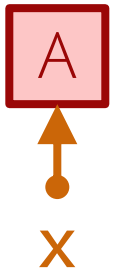
SL assertions

empty heap	{ emp }
singleton heap	{ y ↦ 5 }
separating conjunction	{ x ↦ y * y ↦ 5 }
memory block	{ [x, 2] * x ↦ 5 * (x + 1) ↦ 10 }

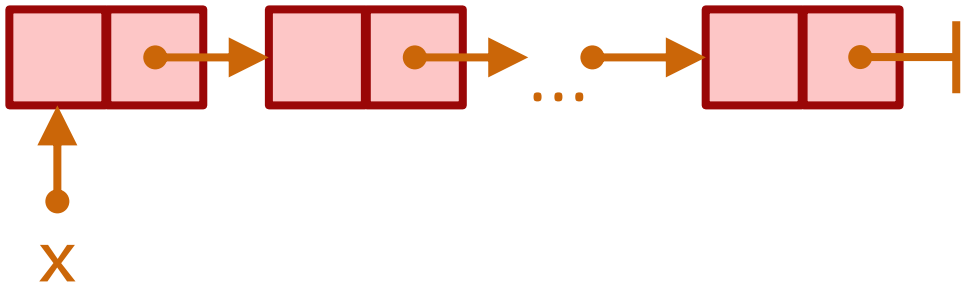


SL assertions

empty heap	{ emp }
singleton heap	{ y ↦ 5 }
separating conjunction	{ x ↦ y * y ↦ 5 }
memory block	{ [x, 2] * x ↦ 5 * (x + 1) ↦ 10 }
+ pure formula	{ A > 5 ; x ↦ A }



SL assertions: linked structures

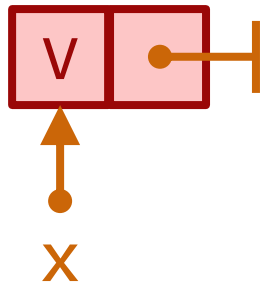


SL assertions: linked structures

linked list $\{ x = 0 ; emp \}$

SL assertions: linked structures

linked list $\{ [x, 2] * x \mapsto V * (x + 1) \mapsto 0 \}$

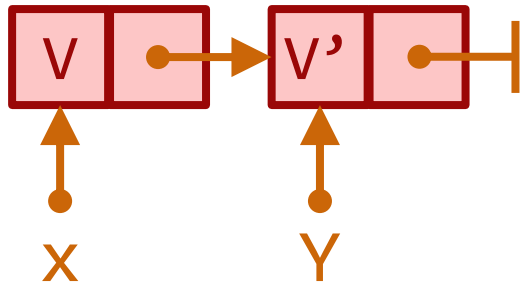


SL assertions: linked structures

linked list $\{ [x, 2] * x \mapsto V * (x + 1) \mapsto Y *$

$[Y, 2] * Y \mapsto V' * (Y + 1) \mapsto 0$

$\}$



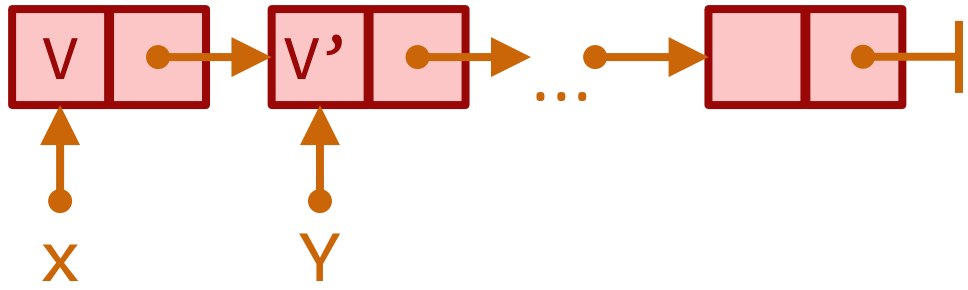
SL assertions: linked structures

linked list $\{ [x, 2] * x \mapsto V * (x + 1) \mapsto Y *$

$[Y, 2] * Y \mapsto V' * (Y + 1) \mapsto Y' *$

…

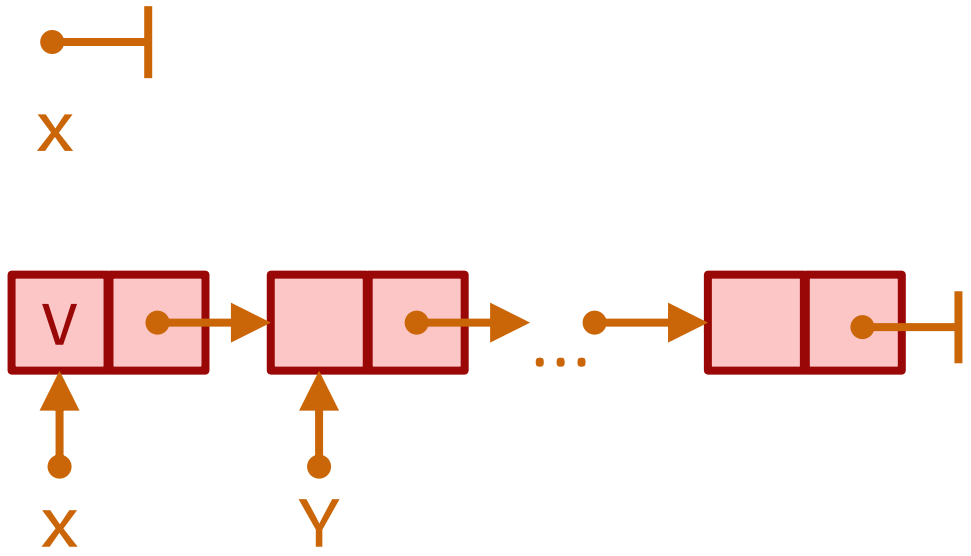
$\}$



inductive predicates to the rescue!

The linked list predicate

```
predicate list (loc x) {
  |  x = 0  =>  { emp }
  |  x ≠ 0  =>  { [x, 2]
                  * x ↦ V
                  * (x + 1) ↦ Y
                  *  list(Y)
                }
}
```



Outline

example: swap

separation logic

2.1. programs

2.2. assertions

2.3. specifying data transformations

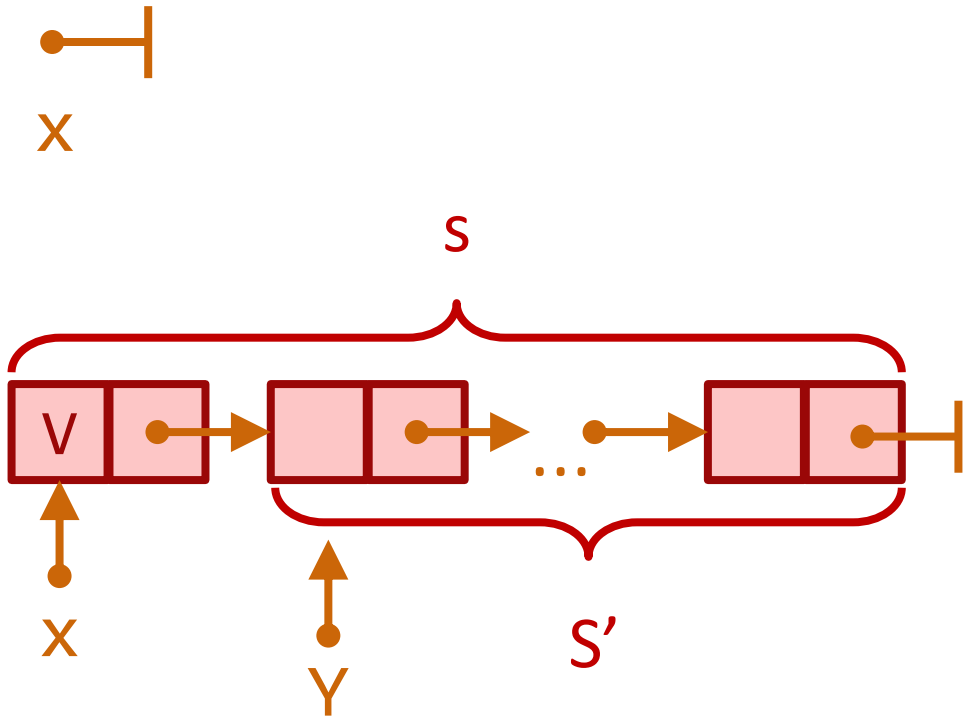
deductive synthesis

Demo: dispose a list

```
void dispose(loc x)
{ list(x) }
{ emp }
```

Linked list with elements

```
predicate list (loc x, set s) {
  |  x = 0  =>  { s = ∅ ; emp }
  |  x ≠ 0  =>  { s = {V} + S' ;
                  [x, 2]
                  ∗ x ↦ V ∗ (x + 1) ↦ Y
                  ∗  list(Y, S') }
}
```



Demo: copy a list

```
void copy(loc x, loc r)
```

{ list(x, S) * r ↦ _ }

{ list(x, S) * r ↦ Y * list(Y, S) }

return location

Outline

example: swap

the logic

deductive synthesis

Deductive synthesis

synthesis as proof search

this talk

example: swap

the logic

deductive synthesis

3.1. proof system

3.2. proof search

transforming entailment

$$P \rightsquigarrow Q \mid c$$

a state that satisfies P
can be transformed into a state that satisfies Q
using a program **c**

Synthetic separation logic (SSL)

proof system for
transforming entailment

$$\{\mathsf{emp}\} \rightsquigarrow \{\mathsf{emp}\} \mid \; ??$$

(Emp)

$$\{emp\} \rightsquigarrow \{emp\} \mid \mathbf{skip}$$

(Frame)

$$\frac{\{\,P\,\} \rightsquigarrow \{\,Q\,\} \mid c}{\{\,P * R\,\} \rightsquigarrow \{\,Q * R\,\} \mid ??}$$

(Write)

$$\frac{\{\, x \mapsto e * P \,\} \rightsquigarrow \{\, x \mapsto e * Q \,\} \mid c}{\{\, x \mapsto \_ * P \,\} \rightsquigarrow \{\, x \mapsto e * Q \,\} \mid ??}$$

(Read)

$$\frac{[y/A]\{\, x \mapsto A * P \,\} \rightsquigarrow [y/A]\{\, Q \,\} \mid c}{\{\, x \mapsto A * P \,\} \rightsquigarrow \{\, Q \,\} \mid ??}$$

SSL: basic rules

(Emp)

$$\{\mathsf{emp}\} \rightsquigarrow \{\mathsf{emp}\} \mid \mathbf{skip}$$

(Read)

$$\frac{[y/A]\{\, x \mapsto A * P \,\} \rightsquigarrow [y/A]\{\, Q \,\} \mid c}{\{\, x \mapsto A * P \,\} \rightsquigarrow \{\, Q \,\} \mid \mathbf{let}\ y = *x;\ c}$$

(Frame)

$$\frac{\{\, P \,\} \rightsquigarrow \{\, Q \,\} \mid c}{\{\, P * R \,\} \rightsquigarrow \{\, Q * R \,\} \mid c}$$

(Write)

$$\frac{\{\, x \mapsto e * P \,\} \rightsquigarrow \{\, x \mapsto e * Q \,\} \mid c}{\{\, x \mapsto \_ * P \,\} \rightsquigarrow \{\, x \mapsto e * Q \,\} \mid *x = e;\ c}$$

Example: swap

$$\{ x \mapsto A * y \mapsto B \} \rightsquigarrow \{ x \mapsto B * y \mapsto A \} \mid \quad ??$$

$$\{\, x \mapsto A * y \mapsto B \,\} \rightsquigarrow \{\, x \mapsto B * y \mapsto A \,\} \mid \quad ??$$

$$\frac{\{\, x \mapsto a1 * y \mapsto B \,\} \rightsquigarrow \{\, x \mapsto B * y \mapsto a1 \,\} \mid \; ??}{\{\, x \mapsto A * y \mapsto B \,\} \rightsquigarrow \{\, x \mapsto B * y \mapsto A \,\} \mid \; \texttt{let a1 = *x; ??}} \text{ (Read)}$$

$$\frac{\{\, x \mapsto a1 * y \mapsto b1 \,\} \rightsquigarrow \{\, x \mapsto b1 * y \mapsto a1 \,\} \mid \texttt{??}}{\{\, x \mapsto a1 * y \mapsto B \,\} \rightsquigarrow \{\, x \mapsto B * y \mapsto a1 \,\} \mid \texttt{let b1 = *y; ??}}\ \text{(Read)}$$

$$\frac{\{\, x \mapsto a1 * y \mapsto B \,\} \rightsquigarrow \{\, x \mapsto B * y \mapsto a1 \,\} \mid \texttt{let b1 = *y; ??}}{\{\, x \mapsto A * y \mapsto B \,\} \rightsquigarrow \{\, x \mapsto B * y \mapsto A \,\} \mid \texttt{let a1 = *x; ??}}\ \text{(Read)}$$

$$\{\, x \mapsto b1 * y \mapsto b1 \,\} \rightsquigarrow \{\, x \mapsto b1 * y \mapsto a1 \,\} \mid \texttt{??}$$

(Write)

$$\{\, x \mapsto a1 * y \mapsto b1 \,\} \rightsquigarrow \{\, x \mapsto b1 * y \mapsto a1 \,\} \mid \texttt{*x = b1; ??}$$

(Read)

$$\{\, x \mapsto a1 * y \mapsto B \,\} \rightsquigarrow \{\, x \mapsto B * y \mapsto a1 \,\} \mid \texttt{let b1 = *y; ??}$$

(Read)

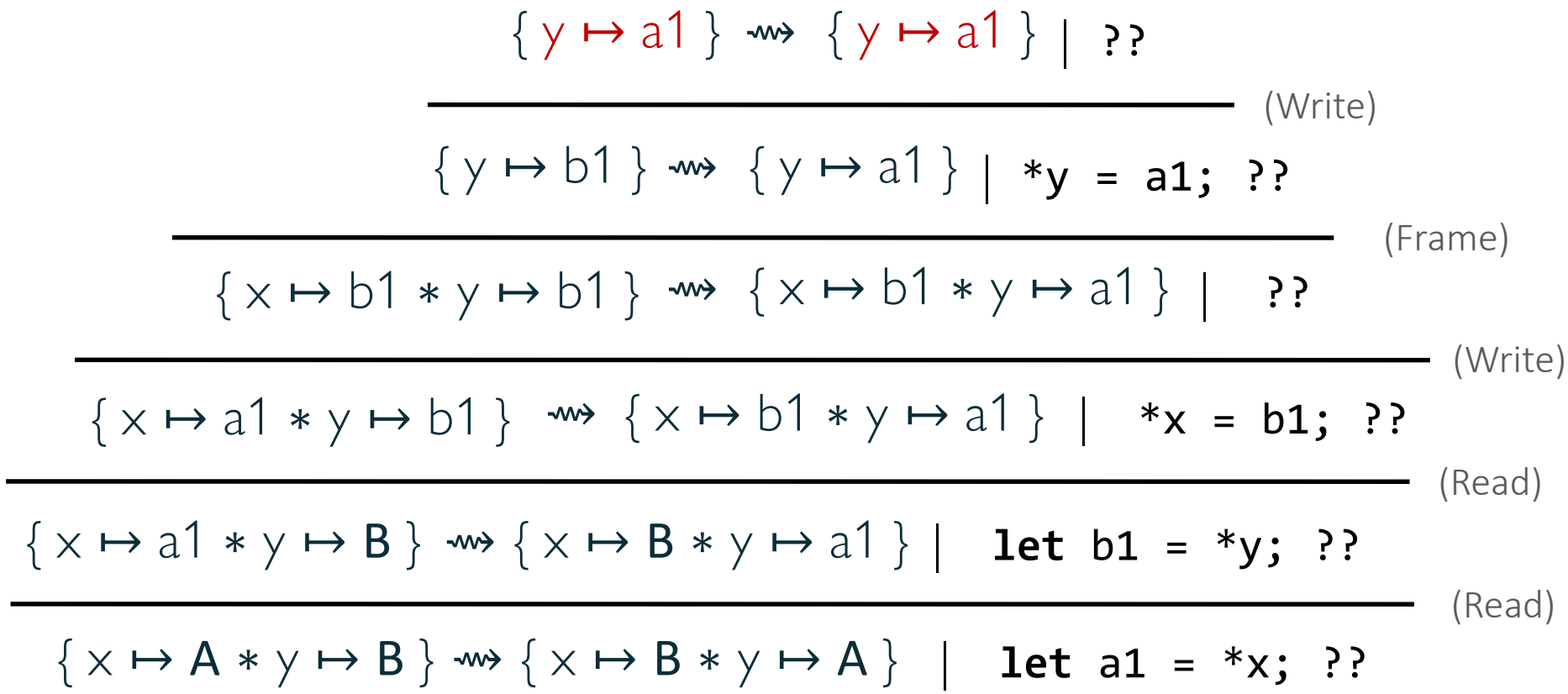
$$\{\, x \mapsto A * y \mapsto B \,\} \rightsquigarrow \{\, x \mapsto B * y \mapsto A \,\} \mid \texttt{let a1 = *x; ??}$$

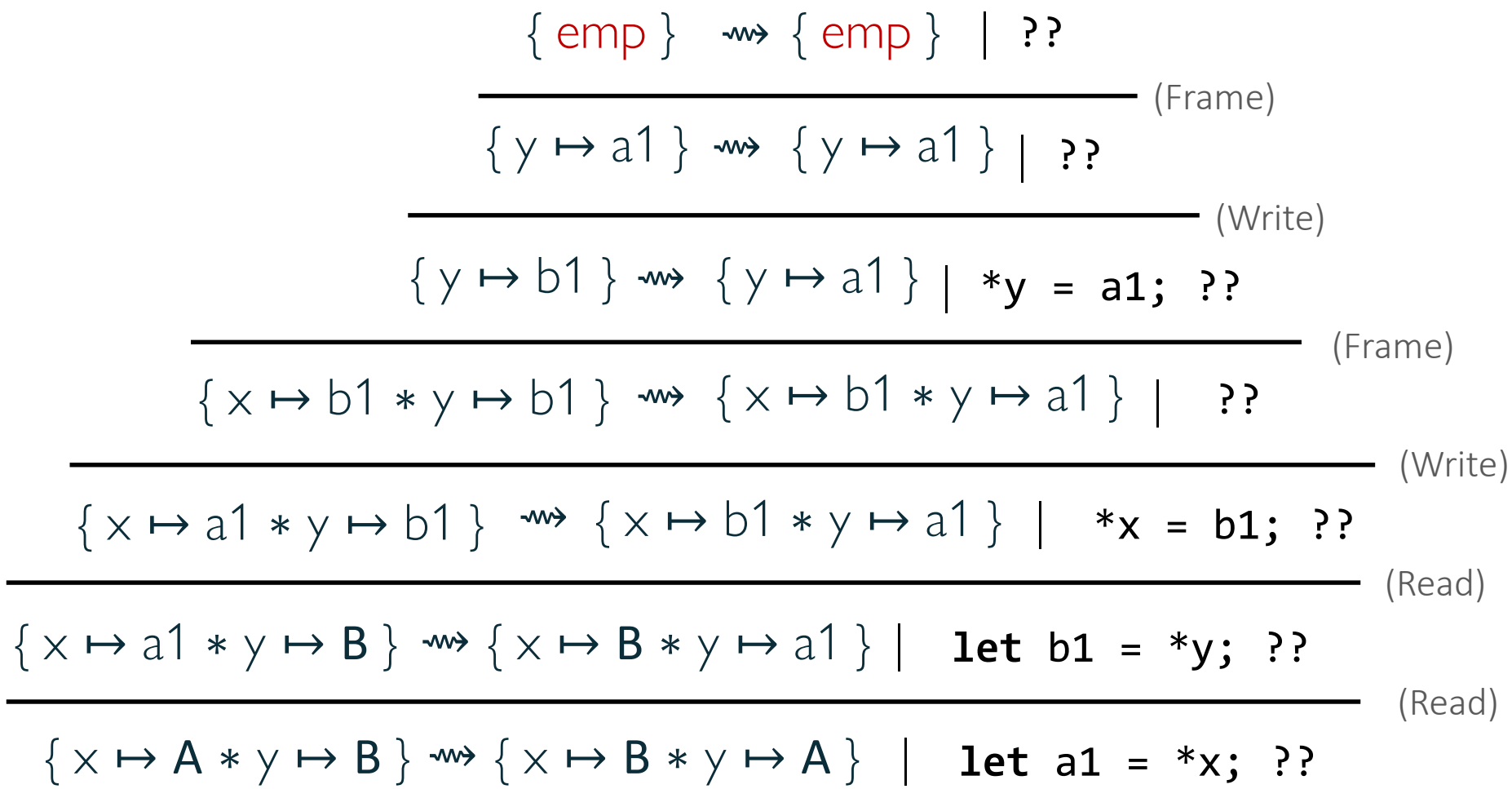
$$\frac{\{\, y \mapsto b1 \,\} \rightsquigarrow \{\, y \mapsto a1 \,\} \mid \texttt{??}}{\{\, x \mapsto b1 * y \mapsto b1 \,\} \rightsquigarrow \{\, x \mapsto b1 * y \mapsto a1 \,\} \mid \texttt{??}}\ \text{(Frame)}$$

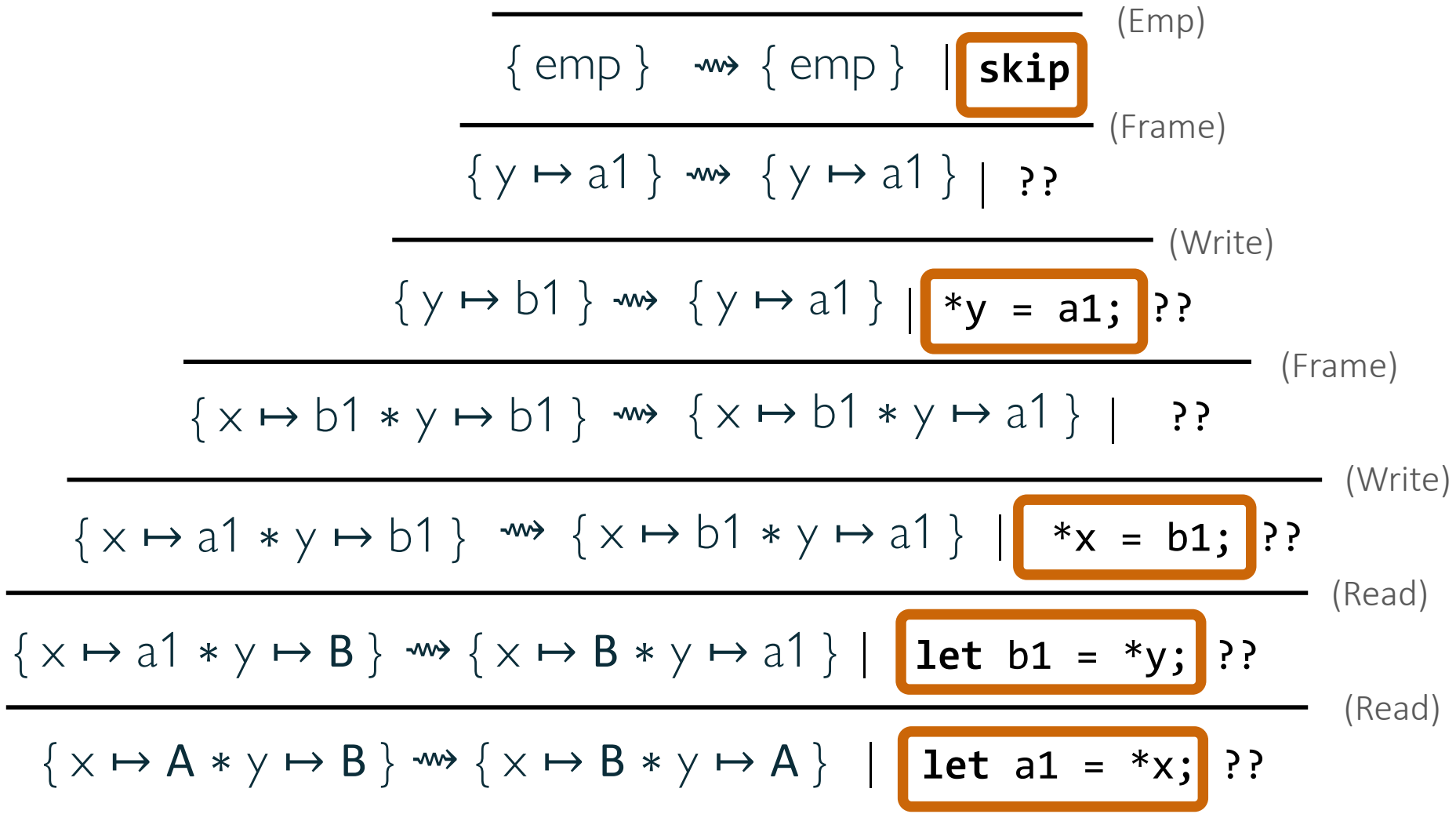
$$\frac{\{\, x \mapsto b1 * y \mapsto b1 \,\} \rightsquigarrow \{\, x \mapsto b1 * y \mapsto a1 \,\} \mid \texttt{??}}{\{\, x \mapsto a1 * y \mapsto b1 \,\} \rightsquigarrow \{\, x \mapsto b1 * y \mapsto a1 \,\} \mid \texttt{*x = b1; ??}}\ \text{(Write)}$$

$$\frac{\{\, x \mapsto a1 * y \mapsto b1 \,\} \rightsquigarrow \{\, x \mapsto b1 * y \mapsto a1 \,\} \mid \texttt{*x = b1; ??}}{\{\, x \mapsto a1 * y \mapsto B \,\} \rightsquigarrow \{\, x \mapsto B * y \mapsto a1 \,\} \mid \texttt{let b1 = *y; ??}}\ \text{(Read)}$$

$$\frac{\{\, x \mapsto a1 * y \mapsto B \,\} \rightsquigarrow \{\, x \mapsto B * y \mapsto a1 \,\} \mid \texttt{let b1 = *y; ??}}{\{\, x \mapsto A * y \mapsto B \,\} \rightsquigarrow \{\, x \mapsto B * y \mapsto A \,\} \mid \texttt{let a1 = *x; ??}}\ \text{(Read)}$$


{ y ↦ a1 } ⇝ { y ↦ a1 } | ??
(Write)
{ y ↦ b1 } ⇝ { y ↦ a1 } | *y = a1; ??
(Frame)
{ x ↦ b1 ∗ y ↦ b1 } ⇝ { x ↦ b1 ∗ y ↦ a1 } | ??
(Write)
{ x ↦ a1 ∗ y ↦ b1 } ⇝ { x ↦ b1 ∗ y ↦ a1 } | *x = b1; ??
(Read)
{ x ↦ a1 ∗ y ↦ B } ⇝ { x ↦ B ∗ y ↦ a1 } | let b1 = *y; ??
(Read)
{ x ↦ A ∗ y ↦ B } ⇝ { x ↦ B ∗ y ↦ A } | let a1 = *x; ??


{ emp } ⇝ { emp } | ??
(Frame)
{ y ↦ a1 } ⇝ { y ↦ a1 } | ??
(Write)
{ y ↦ b1 } ⇝ { y ↦ a1 } | *y = a1; ??
(Frame)
{ x ↦ b1 ∗ y ↦ b1 } ⇝ { x ↦ b1 ∗ y ↦ a1 } | ??
(Write)
{ x ↦ a1 ∗ y ↦ b1 } ⇝ { x ↦ b1 ∗ y ↦ a1 } | *x = b1; ??
(Read)
{ x ↦ a1 ∗ y ↦ B } ⇝ { x ↦ B ∗ y ↦ a1 } | let b1 = *y; ??
(Read)
{ x ↦ A ∗ y ↦ B } ⇝ { x ↦ B ∗ y ↦ A } | let a1 = *x; ??


{ emp } ⇝ { emp } | skip
(Emp)
(Frame)
{ y ↦ a1 } ⇝ { y ↦ a1 } | ??
(Write)
{ y ↦ b1 } ⇝ { y ↦ a1 } | *y = a1; ??
(Frame)
{ x ↦ b1 * y ↦ b1 } ⇝ { x ↦ b1 * y ↦ a1 } | ??
(Write)
{ x ↦ a1 * y ↦ b1 } ⇝ { x ↦ b1 * y ↦ a1 } | *x = b1; ??
(Read)
{ x ↦ a1 * y ↦ B } ⇝ { x ↦ B * y ↦ a1 } | let b1 = *y; ??
(Read)
{ x ↦ A * y ↦ B } ⇝ { x ↦ B * y ↦ A } | let a1 = *x; ??

$\{ x \mapsto A * y \mapsto B \}$

```
let a1 = *x; let b1 = *y; *x = b1; *y = a1; skip
```

$\{ x \mapsto B * y \mapsto A \}$

Synthetic separation logic (SSL)

basic rules

(Emp), (Read), (Write), (Frame)
(Alloc), (Free)

pure reasoning and unification

inductive predicates and recursion

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Example: dispose a list

```
void dispose(loc x)
```

{ list(x) }

{ emp }

{ list^1 (x) } **void** dispose(**loc** x) { emp }

{ list^0(x) }

??

(Induction)

{ emp }

predicate list (loc x) {
| x = 0 => { emp }
| x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ $list^1$ (x) } **void** dispose(**loc** x) { emp }

{ $list^0(x)$ }

??

(Open)

{ emp }

predicate list (loc x) {
| x = 0 => { emp }
| x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list¹ (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) {
```
{ x = 0 ; emp }

```
??
```
{ emp }

```
} else {
```
{ x ≠ 0 ; [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list¹ (Y) }

```
??
```
{ emp }

```
}
```

predicate list (loc x) {
| x = 0 => { emp }
| x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list^{1} (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) {
```

{ x = 0 ; emp }

?? (Emp)

{ emp }

```
} else {
```

{ x ≠ 0 ; [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list^{1} (Y) }

??

{ emp }

}

predicate list (loc x) {
  | x = 0 => { emp }
  | x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list^{1} (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) {
```

{ x = 0 ; emp }

```
    skip
```

{ emp }

```
} else {
```

{ x ≠ 0 ; [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list^{1} (Y) }

```
    ??
```

{ emp }

```
}
```

predicate list (loc x) {
  | x = 0 => { emp }
  | x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list^{1} (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) { skip } else {
```

{ x ≠ 0 ; [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list^{1} (Y) }

```
    ??
```

{ emp }

}

predicate list (loc x) {
  | x = 0 => { emp }
  | x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list^{1} (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) { skip } else {
```

{ x ≠ 0 ; [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list^{1} (Y) }

```
    ??
```

{ emp }

```
}
```

(Read)

predicate list (loc x) {
  | x = 0 => { emp }
  | x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list^1 (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) { skip } else {
    let y1 = *(x + 1);
```

{ x ≠ 0 ; [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ y1 ∗ list^1 (y1) }

```
    ??
```

{ emp }

}

predicate list (loc x) {
  | x = 0 => { emp }
  | x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list^{1} (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) { skip } else {
    let y1 = *(x + 1);
```

{ x ≠ 0 ; [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ y1 ∗ list^{1} (y1) }

```
    ??
```

(Free)

{ emp }

}

predicate list (loc x) {
  | x = 0 => { emp }
  | x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list^{1} (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) { skip } else {
    let y1 = *(x + 1);
    free x;
```

{ x ≠ 0 ; list^{1} (y1) }

```
    ??
```

{ emp }

}

predicate list (loc x) {
  | x = 0 => { emp }
  | x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list^1 (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) { skip } else {
    let y1 = *(x + 1);
    free x;
```

{ x ≠ 0 ; list^1 (y1) }

(Call)

```
    ??
```

{ emp }

}

predicate list (loc x) {
  | x = 0 => { emp }
  | x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list^{1} (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) { skip } else {
    let y1 = *(x + 1);
    free x;
    dispose(y1);
{ x ≠ 0 ; emp }
     ??
{ emp }
}
```

predicate list (loc x) {
  | x = 0 => { emp }
  | x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list^{1} (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) { skip } else {
    let y1 = *(x + 1);
    free x;
    dispose(y1);
```

{ x ≠ 0 ; emp }

```
    ??
```

{ emp }

```
}
```

(Emp)

predicate list (loc x) {
  | x = 0 => { emp }
  | x ≠ 0 => { [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ Y ∗ list(Y) }
}

{ list^{1} (x) } **void** dispose(**loc** x) { emp }

```
if (x == 0) { skip } else {
    let y1 = *(x + 1);
    free x;
    dispose(y1);
    skip


}
```

```
void dispose(loc x) {
  if (x == 0) { }
  else {
    let y1 = *(x + 1);
    free x;
    dispose(y1)
  }
}
```

Synthetic separation logic (SSL)

basic rules

(Emp), (Read), (Write), (Frame), (Alloc), (Free)

pure reasoning and unification

inductive predicates and recursion

(Open), (Close), (Induction), (Call)

Outline

example: swap

the logic

deductive synthesis

3.1. proof system

3.2. proof search

SuSLik

best-first and-or search in SSL

+ optimizations

Optimizations

invertible rules

early failure

multi-phase search

goal memoization

Optimization: invertible rules

invertible rules do not restrict the set of derivable programs

idea: invertible rules need not be backtracked

(Read)

$$\frac{[y/A]\{\ x \mapsto A * P\ \} \rightsquigarrow [y/A]\{\ Q\ \} \mid c}{\{\ x \mapsto A * P\ \} \rightsquigarrow \{\ Q\ \} \mid \texttt{let}\ y = *x;\ c}$$

Optimization: early failure

idea: sometimes you know that a goal is unsatisfiable

(Post-Inconsistent)

$$\frac{\psi \neq \bot \qquad \vdash \phi \wedge \psi \Rightarrow \bot \qquad \{\ \mathsf{emp}\ \} \rightsquigarrow \{\ \bot\ ;\ \mathsf{emp}\ \} \mid c}{\{\ \phi\ ;\ P\ \} \rightsquigarrow \{\ \psi\ ;Q\ \} \mid c}$$

Optimization: multi-phase search

unfolding phase: eliminates inductive predicates
(Open), (Close), (Call), (Unify) , (Frame)

block phase: eliminates blocks
(Alloc), (Free), (Unify), (Frame)

pointer phase: aligns all pointers
(Unify), (Frame)

pure phase: deals with the content of pointers
(Write), (Unify), (Pure)

idea: if a phase fails, don't start the next one

SuSLik: contributions

Synthesis with unbounded guarantees for recursive heap-manipulating programs

Does not require sketches

Optimizations from proof search

SuSLik: limitations

No auxiliary functions

Only structurally recursive programs

Requires the spec to be inductive

Does not support loops

- But we can turn recursion into loops (?)

Requires SL expertise

SuSLik: questions

Behavioral constraints? Structural constraints? Search strategy?

- SL specs
- Set of components + built-in language constraints
- Deductive search

Enumerative vs deductive search

- Enumerative = enumerates programs
- Deductive = enumerates derivations
- Synquid can be seen as deductive search in the space of typing derivations

SuSLik: questions

Why is Frame rule not invertible?

- What other rule can it prevent from applying?

$$\text{(Frame)}\quad \frac{\{\ P\ \} \rightsquigarrow \{\ Q\ \} \mid \mathsf{c}}{\{\ P * R\ \} \rightsquigarrow \{\ Q * R\ \} \mid \mathsf{c}}$$