Lecture 13
Separation Logic and Deductive Synthesis

Today

Behavioral constraints

assertions   + bounded guarantees
types   + unbounded guarantees
pre/post-conditions

Program space

Search strategy

constraint-based
deductive

imperative programs w/ loops
recursive functional programs
recursive pointer-manipulating programs
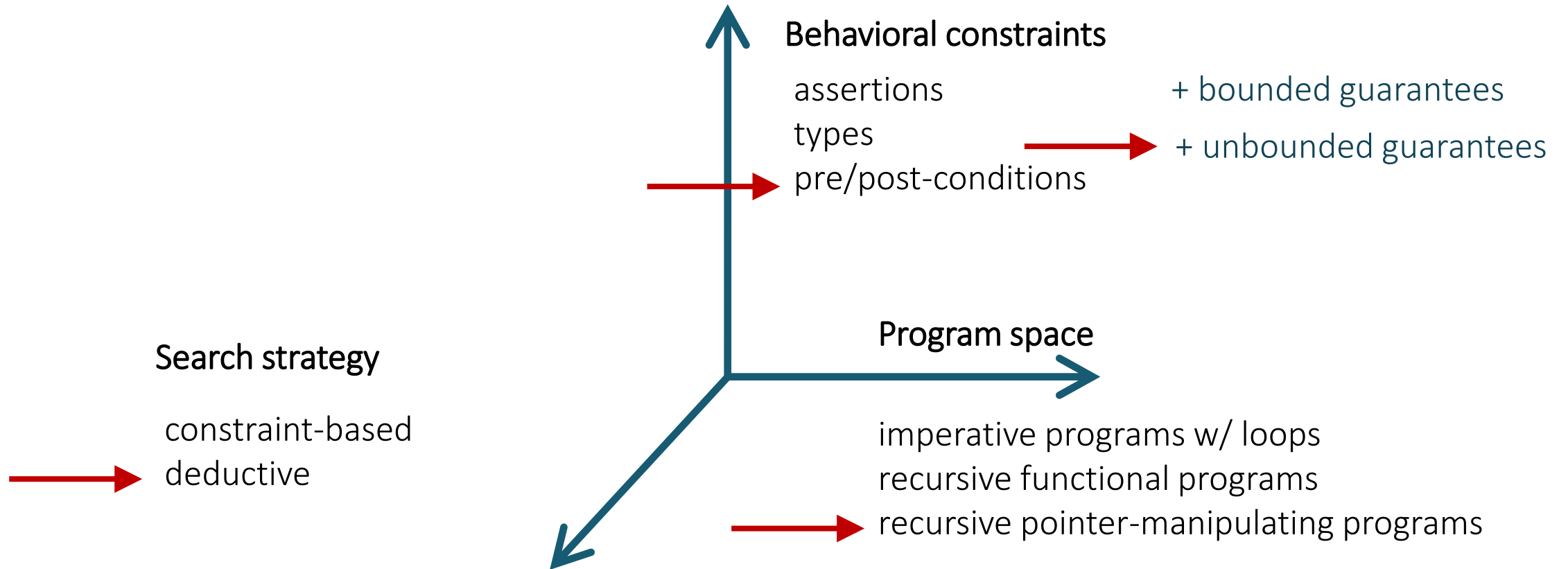
Program synthesis

specification

code

Program synthesis

specification
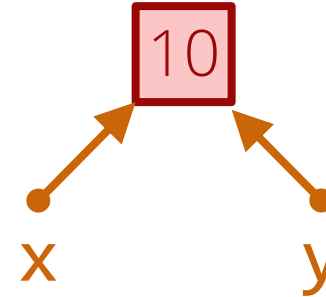
C code?

☹ verbose
☹ unstructured
☹ pointers

The trouble with pointers

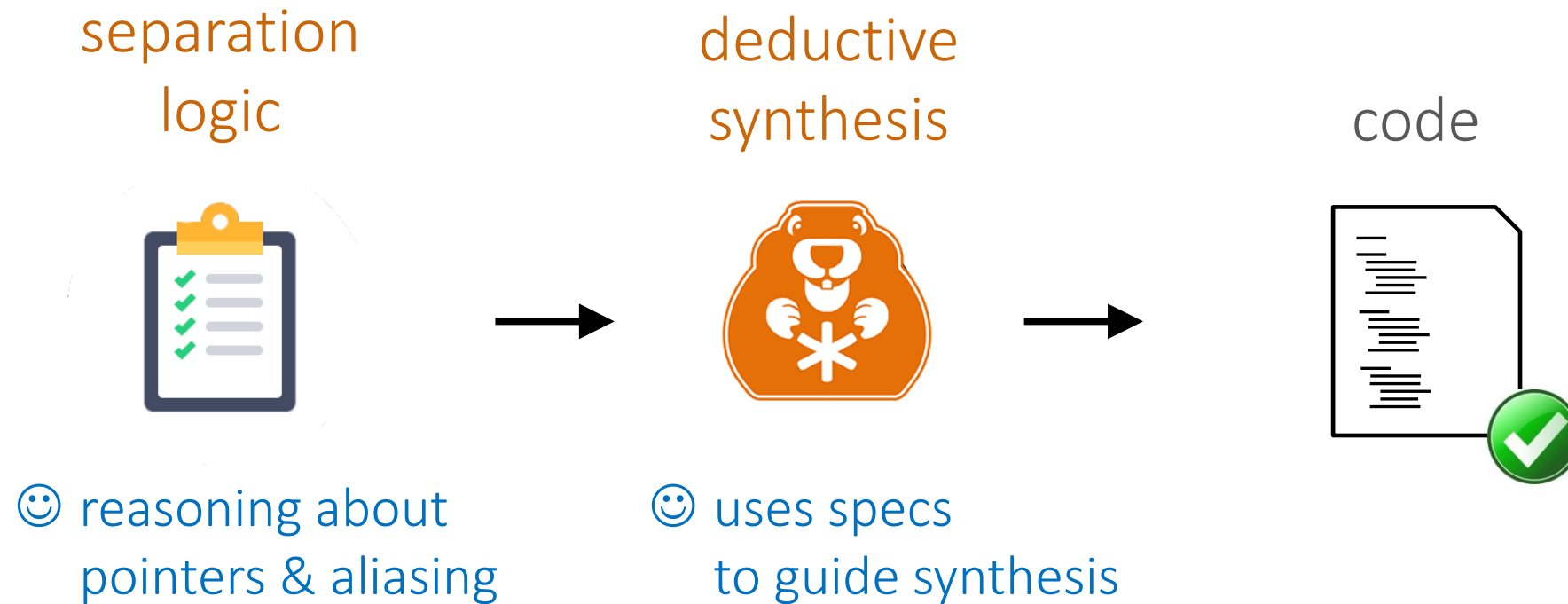Can we naively apply Hoare logic to programs with pointers?

$\{* x = 10 \land * y = 10\}$
$\quad \Rightarrow$
$\{* x + 5 = 15 \land * y - 5 = 5\}$

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

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

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

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

SuSLik

Synthesis Using Separation Logik

The SuSLik approach

separation
logic

deductive
synthesis

code

☺ reasoning about
pointers & aliasing

☺ uses specs
to guide synthesis

Outline

example: swap

a taste of SuSLik

separation logic

specifying pointer-manipulating programs

deductive synthesis

from SL specifications to programs

Outline

example: swap
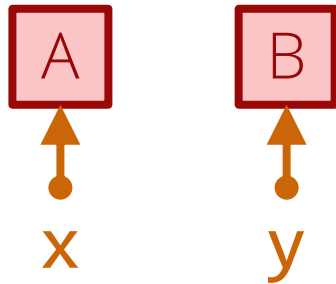
separation logic

deductive synthesis
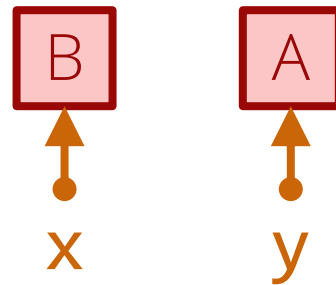
Example: swap

Swap values of two *distinct* pointers

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

Example: swap

start state:

end state:

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

separately

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

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

ghost variables

11

Demo: swap

Swap values of two *distinct* pointers

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

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

? ?

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

let a1 = *x;

{ x ↦ a1 * y ↦ B }

??

{ x ↦ B * y ↦ a1 }

let a1 = *x;

let b1 = *y;

{ x ↦ a1 * y ↦ b1 }

??

{ x ↦ b1 * y ↦ a1 }

```
let a1 = *x;

let b1 = *y;

*x = b1;
```

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

??

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

```
let a1 = *x;

let b1 = *y;

*x = b1;

*y = a1;
```

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

??   same

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

```
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)

SL assertions

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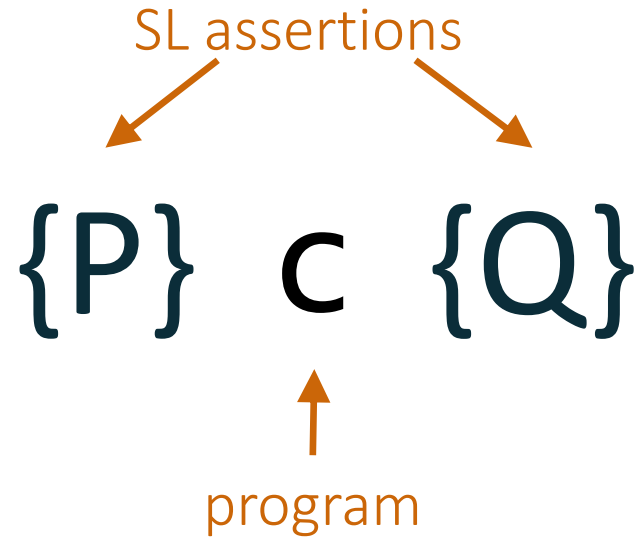
program

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

offset (natural number)

do nothing **skip**

read from heap **let** y = *(x + n)

variables

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$_1$, ..., 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	$p(e_1, ..., e_n)$
~~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$_1$, ..., e$_n$)
sequential composition	c$_1$; c$_2$
conditional	**if** (e) {c$_1$} else {c$_2$}

Outline

example: swap

separation logic

deductive synthesis

Separation logic (SL)

SL assertions

$\{P\}$ c $\{Q\}$
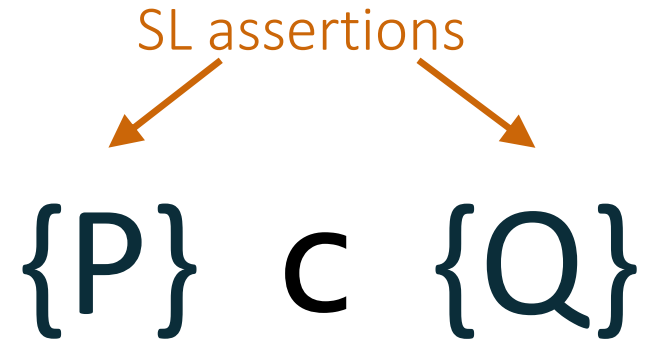
SL assertions

empty heap   { emp }

SL assertions

empty heap   { emp }

singleton heap   { y $\mapsto$ 5 }

$$5$$

y

SL assertions

empty heap   { emp }

singleton heap   { $y \mapsto 5$ }

separating   { $x \mapsto y$ * $y \mapsto 5$ }
conjunction

heaplets

x   y

5

SL assertions

empty heap   { emp }

singleton heap   { y ↦ 5 }

separating   { x ↦ y * y ↦ 5 }
conjunction

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 }
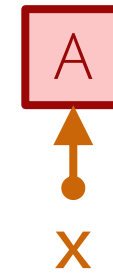
SL assertions: linked structures
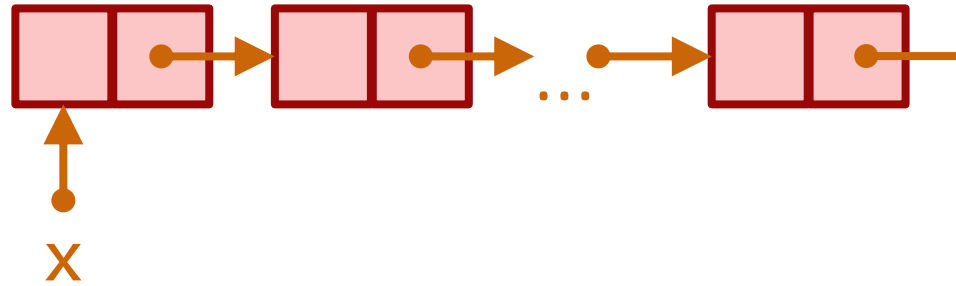
SL assertions: linked structures

linked list   { x = 0 ; emp }

x

SL assertions: linked structures

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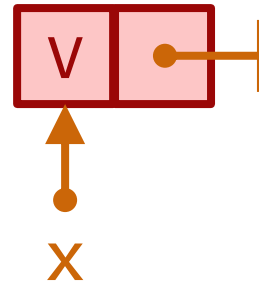
SL assertions: linked structures

linked list

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

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

$\}$
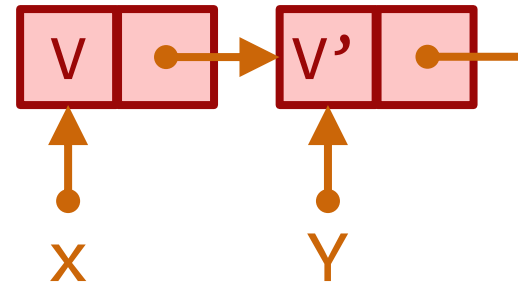
SL assertions: linked structures

linked list

{ [x, 2] * x ↦ V * (x + 1) ↦ Y *

[Y, 2] * Y ↦ V' * (Y + 1) ↦ Y' *

...

}
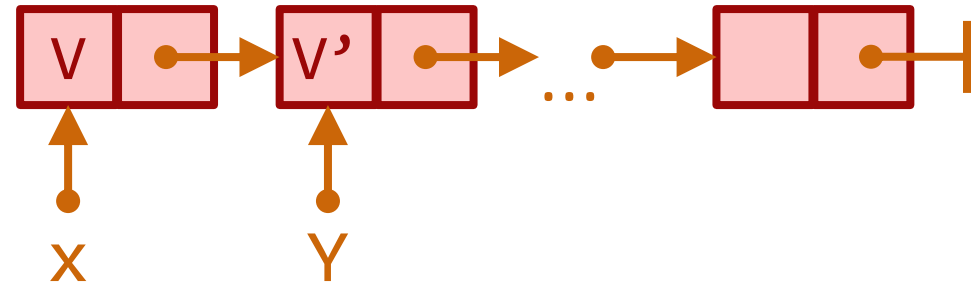
inductive predicates to the rescue!

The linked list predicate

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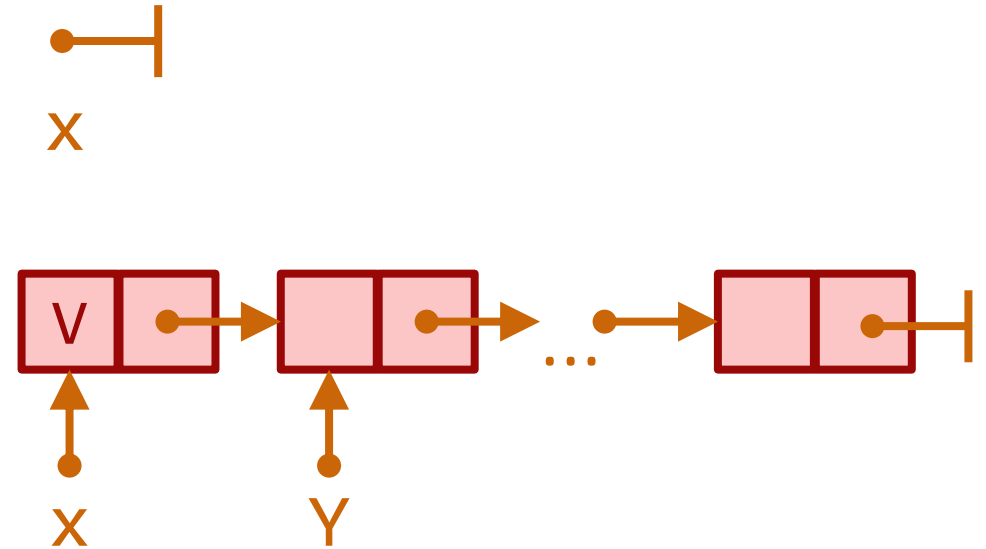
Outline

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') }
}
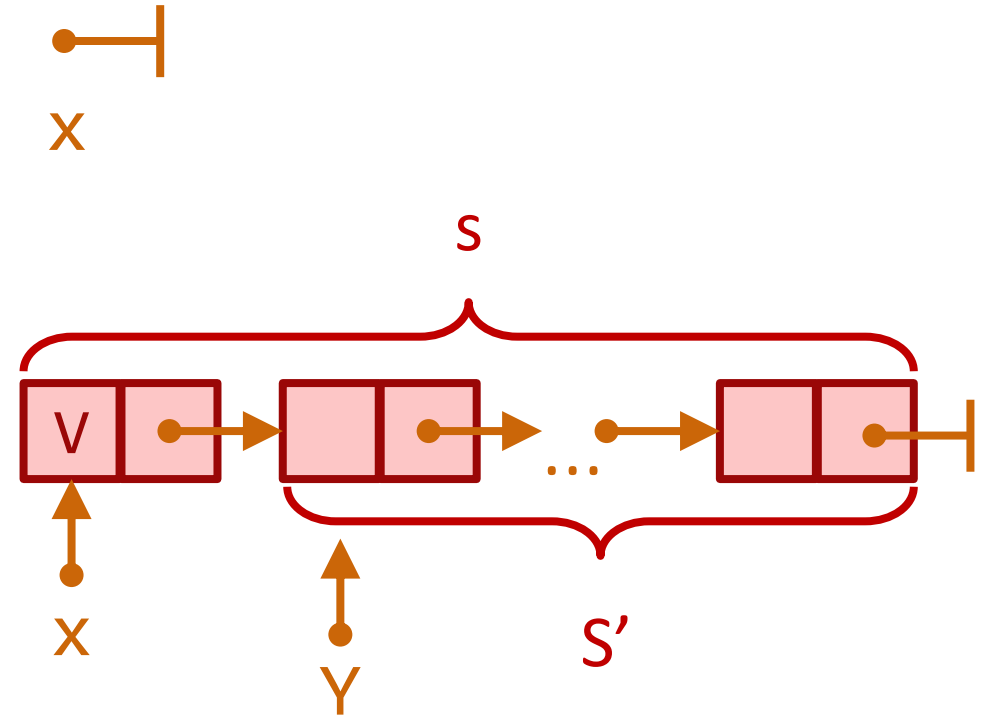
Demo: copy a list

```
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

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

(Emp)

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

(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)

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

$$\rule{8cm}{0.4pt}$$

$$\{ x \mapsto A * P \} \rightsquigarrow \{ Q \} \qquad \mid \text{ ??}$$

SSL: basic rules

(Emp)

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

(Read)

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

(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

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

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

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

$$\{ x \mapsto a1 * y \mapsto b1 \} \rightsquigarrow \{ \textcolor{red}{x \mapsto b1} * y \mapsto a1 \} \mid \ ??$$

_____ (Read)

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

_____ (Read)

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

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

_____ (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)

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

$$\{\, y \mapsto b1 \,\} \rightsquigarrow \{\, \textcolor{red}{y \mapsto a1} \,\} \mid \; ??$$

———————————————————————— (Frame)

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

———————————————————————— (Write)

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

———————————————————————— (Read)

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

———————————————————————— (Read)

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

$$\{\, y \mapsto a1 \,\} \rightsquigarrow \{\, y \mapsto a1 \,\} \mid \; ??$$

_____ (Write)

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

_____ (Frame)

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

_____ (Write)

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

_____ (Read)

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

_____ (Read)

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

$$\{\ \text{emp}\ \}\ \leadsto\ \{\ \text{emp}\ \}\ |\ \text{??}$$

—————————————————————— (Frame)

$$\{\ y \mapsto a1\ \}\ \leadsto\ \{\ y \mapsto a1\ \}\ |\ \text{??}$$

—————————————————————— (Write)

$$\{\ y \mapsto b1\ \}\ \leadsto\ \{\ y \mapsto a1\ \}\ |\ \texttt{*y = a1; ??}$$

—————————————————————— (Frame)

$$\{\ x \mapsto b1 * y \mapsto b1\ \}\ \leadsto\ \{\ x \mapsto b1 * y \mapsto a1\ \}\ |\ \text{??}$$

—————————————————————— (Write)

$$\{\ x \mapsto a1 * y \mapsto b1\ \}\ \leadsto\ \{\ x \mapsto b1 * y \mapsto a1\ \}\ |\ \texttt{*x = b1; ??}$$

—————————————————————— (Read)

$$\{\ x \mapsto a1 * y \mapsto B\ \}\ \leadsto\ \{\ x \mapsto B * y \mapsto a1\ \}\ |\ \texttt{let b1 = *y; ??}$$

—————————————————————— (Read)

$$\{\ x \mapsto A * y \mapsto B\ \}\ \leadsto\ \{\ x \mapsto B * y \mapsto A\ \}\ |\ \texttt{let a1 = *x; ??}$$

$$\frac{\qquad\qquad\qquad\qquad\qquad}{\{\,\text{emp}\,\}\ \rightsquigarrow\ \{\,\text{emp}\,\}\ \mid\ \boxed{\textbf{skip}}}\ \text{(Emp)}$$

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

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

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

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

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

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

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

```
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

Synthetic separation logic (SSL)

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

pure reasoning and unification

inductive predicates and recursion

Example: dispose a list

void dispose(**loc** x)

{ list(x) }

{ emp }

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

$\{ \boxed{\text{list}^0(x)} \}$

  ??   (Induction)

{ emp }

predicate list (loc x) {
  | $x = 0$ => { emp }
  | $x \neq 0$ => { [x, 2] $*$ x $\mapsto$ V $*$ (x + 1) $\mapsto$ 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) }
}
```

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

```
        if (x == 0) {

        { x = 0 ;  emp }

              ??                    (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) }
}
```

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

```
        if (x == 0) {

        { x = 0 ;  emp }

              skip

        { 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) { 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) }

(Read)

??

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

{ x ≠ 0 ; [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ y1 ∗ list¹ (y1) }

```
        ??
```

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

{ x ≠ 0 ; [x, 2] ∗ x ↦ V ∗ (x + 1) ↦ y1 ∗ list¹ (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 $\mapsto$ V $*$ (x + 1) $\mapsto$ 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) }
}
```

$\{ \text{list}^1 (x) \}$ **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)

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

Optimization: early failure

idea: sometimes you know that a goal is unsatisfiable

(Post-Inconsistent)

$$\dfrac{\psi \neq \bot \qquad \vdash \phi \wedge \psi \Rightarrow \bot \qquad \{\, \text{emp} \,\} \rightsquigarrow \{\, \bot\, ; \text{emp} \,\} \mid c}{\{\, \phi\, ; P \,\} \rightsquigarrow \{\, \psi\, ; Q \,\} \mid c}$$

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

SuSLik: questions

Why is Frame rule unsound in the presence of assignments?

$$(\text{Frame}) \quad \frac{\{\, P \,\} \rightsquigarrow \{\, Q \,\} \mid c}{\{\, P * R \,\} \rightsquigarrow \{\, Q * R \,\} \mid c} \quad fv(R) \cap mod(c) = \emptyset$$

{ x = 0; y ↦ x }

x := 1

provable with this frame rule, but incorrect!

which side condition should we add to Frame?

{ x = 1; y ↦ x }

SuSLik: questions

Why is Frame rule not invertible?

- What other rule can it prevent from applying?

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