Escape analysis

```
fn f() -> [string] {
  let p = ("a", "b") in
  [p.0^p.1, p.1^p.0]
}
fn main() {
  f()...
}
```

→ does not escape

$\Downarrow$

alloc p on the stack

```
let p = ((0,1), (1,2))
[p.0, p.1]
```

Instr I ::= ... | alloc()

Place p :: $*^{?}x$

$x = \text{alloc}^{A}()$ $\hookrightarrow$ $*x = A$

$*x = 1$

$y = x$ $\qquad *x = *y$

$z = \text{alloc}^{B}()$ $\qquad *z = B$

$*z = y$ $\qquad *z = \alpha,\ *\alpha = *y$

$w = *z$ $\qquad *z = \beta,\ *\beta = *w$

Goal:

map from variables to sets of allocations

$x = \text{alloc}^{A}()$

$x = \text{alloc}^{B}()$

$y = x$

$*x = A = *y = *w$

$*z = B = \alpha = \beta$

$\alpha = \beta \Rightarrow *\alpha = *\beta$

$x = \text{alloc}^{A}()$

$y = \text{alloc}^{B}()$

$z = \text{alloc}^{C}()$

$*z = x \qquad *z = y$

Steensgaard's

$[\![x = \text{alloc}^{A}()]\!] \hookrightarrow A = *y$

$[\![x = y]\!] \hookrightarrow *x = *y$

Andersen's

$[\![x = \text{alloc}^{A}()]\!] \hookrightarrow A \in *x$

$[\![x = y]\!] \hookrightarrow *y \subseteq *x$

$[\![x = *y]\!] \leftrightarrow *y = \alpha,\ *\alpha = *x$

$[\![*x = y]\!] \leftrightarrow *x = \alpha,\ *\alpha = *y$

$[\![x = *y]\!] \leftrightarrow *y = \alpha,\ *\alpha \subseteq *x$

$[\![*x = y]\!] \leftrightarrow *x = \alpha,\ *y \subseteq *\alpha$

$x = \text{alloc}^A()$	$\leftrightarrow A \in *x$	$*x = \{A\}$ $\quad *w = \{A\}$
$*x = 1$		
$y = x$	$*x \subseteq *y$	$*y = \{A\}$
$z = \text{alloc}^B()$	$B \in *z$	$*z = \{B\}$
$*z = y$	$*z = \alpha,\ *y \subseteq *\alpha$	$*y \subseteq *\alpha,\ *\alpha \subseteq *w \Rightarrow *y \subseteq *w$
$w = *z$	$*z = B,\ *B \subseteq *w$	

Will's Algorithm

Instr I ::= ... | alloc$(p_1, \dots p_n)$

Place p ::= $x(.i)^*$

Allocation A

Pointer ptr ::= x | $A.i$

PointsTo $\theta = \{\text{ptr} \mapsto \{A\}\}$

$[\![p_{dst} = \text{alloc}^A(p_1, \dots p_n)]\!] = A \in p_{dst}$, $\quad p_i \subseteq p_{dst}.i$

$[\![p_{dst} = p_{src}]\!] = p_{src} \subseteq p_{dst}$

to a fixpoint:

for $A \in p$ in defs:
  for ptr $\in$ aliases(p):
    add A to θ[ptr]
for $p_{src} \subseteq p_{dst}$ in subsets:
  for ptr_{src} in aliases(p_{src}):
    for ptr_{dst} in aliases(p_{dst}):
      union $\theta[\text{ptr}_{src}]$ into $\theta[\text{ptr}_{dst}]$

aliases$(x) = \{x\}$

aliases$(p.i) = \{$
  $A.i$
  | for ptr $\in$ aliases(p) $\wedge$
  for $A \in \theta$[ptr]$\}$

$\theta = \{x \mapsto \{A\},\ A.0 \mapsto \{B\}\}$

aliases$(x.0) = \{A.0\}$

$x.0 \subseteq y$

$\Theta[A.0] \cup \Theta[y] = \{B\}$

$\Theta = \{x \mapsto \{A, C\},\ A.0 \mapsto \{B\},$
$C.0 \mapsto \{D\}\}$

$\text{aliases}(x.0) = \{A.0, C.0\}$