

15-411: Structs

Jan Hoffmann

Struct Declarations and Definitions

Declaring structs:

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struct s;
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Defining structs:

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struct s { $\tau_1$  f1; ...  $\tau_n$  fn};
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Type

During type derivation we write the following to indicate that field f_i has type τ_i in the definition of s :

$s.f_i : \tau_i$

Small and Large Types

- Arrays are represented with pointers (but cannot be dereferenced)
-> they can be compared and stored in registers
- Structs are usually also pointers but they can be dereferenced
- Structs are large types that do not fit in registers

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Small types:

`int, bool, τ^* , $\tau[]$.`

Large types:

`struct s`

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In C0

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Static Semantics

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- In a given struct definition, all field names must be distinct
- A struct may be defined at most once

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- Struct declarations are optional (but encouraged as good style)
 - An occurrence of struct *s* in a context where its size is irrelevant serves as an implicit declaration of the type struct *s*.

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$$\frac{\Gamma \vdash e : \text{struct } s \quad s.f : \tau}{\Gamma \vdash e.f : \tau}$$

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Dynamic Semantics

Recap: Dynamic Semantics

Transition system that steps between machine states

Machine states (expressions):

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Variable environment

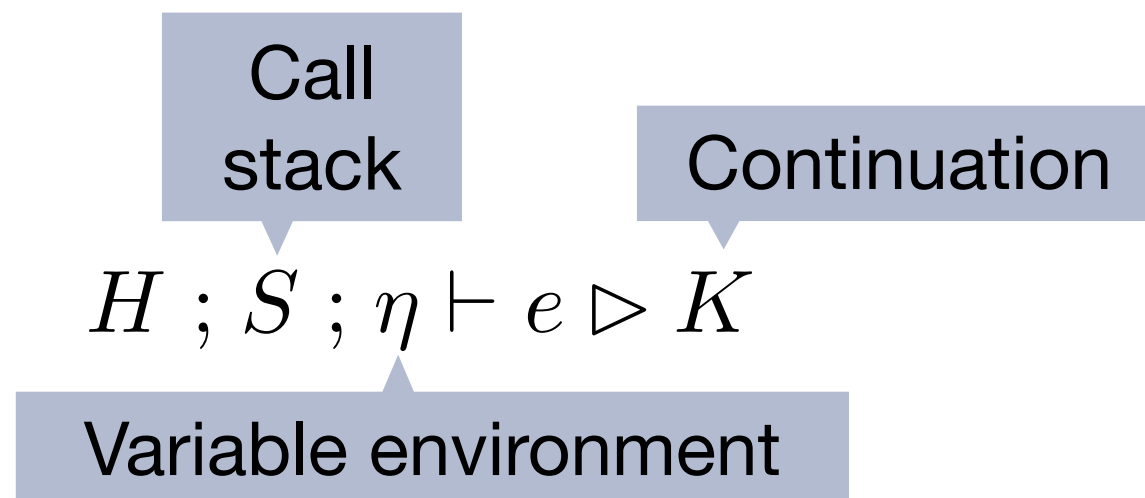
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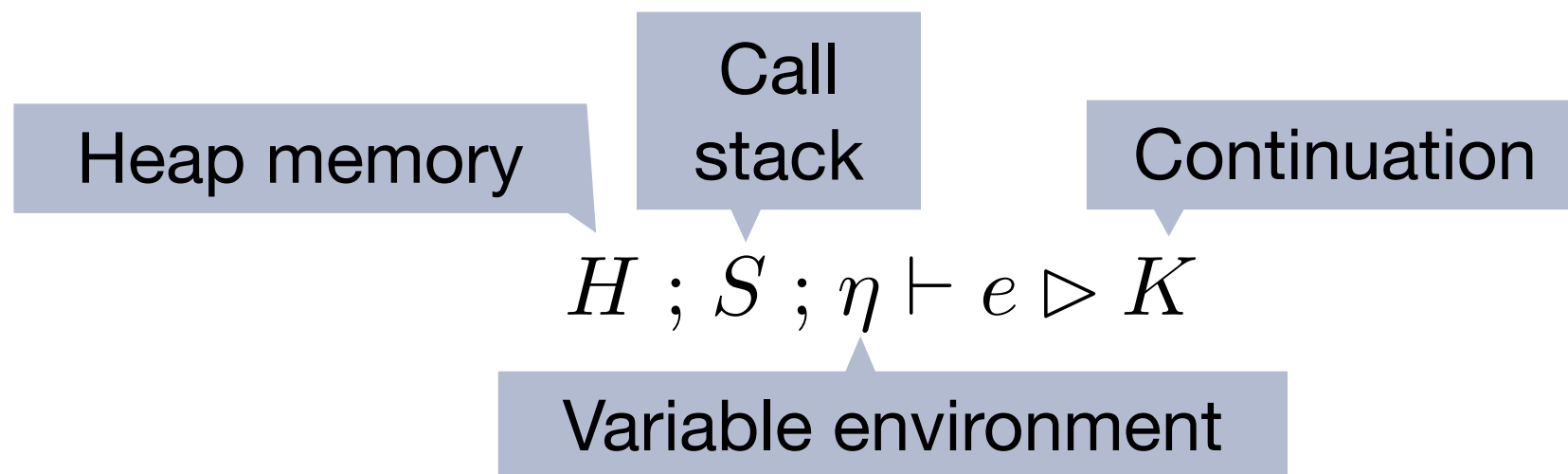
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Variables:

$$H ; S ; \eta \vdash \text{assign}(x, e) \blacktriangleright K \quad \longrightarrow \quad H ; S ; \eta \vdash e \triangleright (\text{assign}(x, _), K)$$

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length(a) = H(a-8)

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Dynamics of Structs: Example

Consider the following program fragment:

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struct point {  
    int x;  
    int y;  
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```

```
struct point* p = alloc(struct point);
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How should the following expressions be evaluated?

$(*p).y$

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Evaluation of Field Access

Option: Evaluate the struct first

$$H ; S ; \eta \vdash e.f \triangleright K \quad \longrightarrow \quad H ; S ; \eta \vdash e \triangleright (_ . y , K)$$

$$H ; S ; \eta \vdash \{x = v_1, y = v_2\} \triangleright (_ . y , K) \quad \longrightarrow \quad H ; S ; \eta \vdash v_2 \triangleright K$$

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Reflect efficient implementation:

- First get the address of struct p
- Take the field offset of y (4 bytes in this case)
- Retrieve integer at address p+4

Type Information and Field Offset

- Like for arrays, we need type information to compute the memory offset of a field
- One way to make the type information available in the dynamics is to annotate each field access in the code with the type of the struct (like we did for array access)

$$e\{\tau_1 f_1; \dots \tau_n f_n; \}.f$$

- Here, e has type struct s , which is defined by `struct s { $\tau_1 f_1; \dots \tau_n f_n; \}$.`
- The following evaluation rules omit this type information to improve readability

'Address Of' Operator

In C we can get the address of a variable `x` and a field `f` using `&`

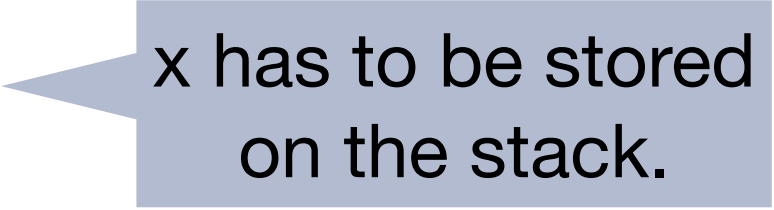
`&(*p).f` `&x`

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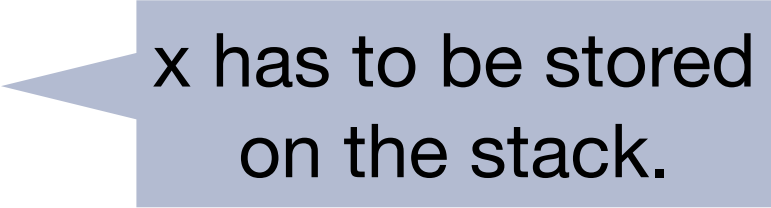
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x has to be stored on the stack.

- In C0 we cannot take the address of values
- This would complicate the semantics
- However, we will use the 'address of' operator in the semantics

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$$H ; S ; \eta \vdash a \triangleright (\&(_ .f) , K) \quad \longrightarrow \quad H ; S ; \eta \vdash a + \text{offset}(s, f) \triangleright K \\ (a \neq 0, a : \text{struct } s)$$

Evaluation of Field Access

- If expression e has a large type, we evaluate $*e$ by evaluating e to an address but we don't dereference it
- This is similar to a destination $*d$ on the left-hand side of an assignment

Rules:

Get the address of $e.f$

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Type info needed

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$a = 0 \text{ or } i < 0 \text{ or } i \geq \text{length}(a)$

Evaluation of Address Operator

These are the only cases in which we can get a large type: field deref, pointer deref, and array access.

$$H ; S ; \eta \vdash \&(*e) \triangleright K \quad \longrightarrow \quad H ; S ; \eta \vdash e \triangleright K$$

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Example: Iteration of Address Calculations

```
struct point {  
    int x;  
    int y;  
};  
struct line {  
    struct point A;  
    struct point B;  
};
```

```
struct line* L = alloc(struct line);  
...  
int x = (*L).B.y;
```

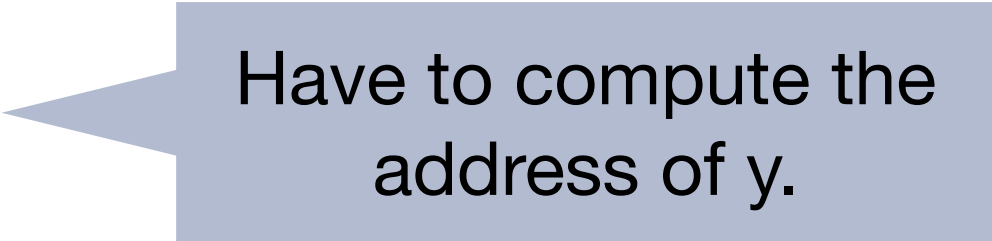
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Have to compute the address of y.

Example: Iteration of Address Calculations

$H ; S ; \eta \vdash \text{assign}(x, (*L).B.y) \blacktriangleright K$

Example: Iteration of Address Calculations

$$\begin{array}{l} H ; S ; \eta \vdash \text{assign}(x, (*L).B.y) \blacktriangleright K \\ \longrightarrow H ; S ; \eta \vdash ((*L).B.y) \triangleright (\text{assign}(x, _), K) \end{array}$$

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- $H ; S ; \eta \vdash \text{assign}(x, (*L).B.y) \blacktriangleright K$
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- $\longrightarrow H ; S ; \eta \vdash L \triangleright (\&(_.B), \&(_.y), *(_), \text{assign}(x, _), K)$

Example: Iteration of Address Calculations

$$\begin{aligned} & H ; S ; \eta \vdash \text{assign}(x, (*L).B.y) \blacktriangleright K \\ \longrightarrow & H ; S ; \eta \vdash ((*L).B.y) \triangleright (\text{assign}(x, _), K) \\ \longrightarrow & H ; S ; \eta \vdash *(&((*L).B.y)) \triangleright (\text{assign}(x, _), K) \\ \longrightarrow & H ; S ; \eta \vdash \&((*L).B.y) \triangleright (*(_), \text{assign}(x, _), K) \\ \longrightarrow & H ; S ; \eta \vdash \&((*L).B) \triangleright (\&(_.y), *(_), \text{assign}(x, _), K) \\ \longrightarrow & H ; S ; \eta \vdash \&(*L) \triangleright (\&(_.B), \&(_.y), *(_), \text{assign}(x, _), K) \\ \longrightarrow & H ; S ; \eta \vdash L \triangleright (\&(_.B), \&(_.y), *(_), \text{assign}(x, _), K) \\ \longrightarrow & H ; S ; \eta \vdash a \triangleright (\&(_.B), \&(_.y), *(_), \text{assign}(x, _), K) \\ & \qquad \qquad \qquad \text{(given that } H ; S ; \eta(L) = a, a \neq 0) \end{aligned}$$

Example: Iteration of Address Calculations

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- $\longrightarrow H ; S ; \eta \vdash a + 8 \triangleright (\&(_.y), *(_), \text{assign}(x, _), K)$
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- $\longrightarrow H ; S ; \eta \vdash a + 12 \triangleright *(_), \text{assign}(x, _), K$
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(given that $H(a + 12) = c$)

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Rules for variable assignments are unchanged.

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Data Sizes

L4 type		size in bytes	C type
int	=	4	int
bool	=	4	int
τ^*	=	8	t *
$\tau[]$	=	8	t *
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C0 and C bools
have size 1 byte.

L4 type	size in bytes	C type
int	= 4	int
bool	= 4	int
τ^*	= 8	t *
$\tau[]$	= 8	t *
struct s	= size(s)	struct s

- Struct sizes are determined by laying out the fields left to right
- Ints and bools are aligned at 0 modulo 4
- Pointers are aligned at 0 modulo 8
- Structs are aligned according to their most restrictive fields

Register Sizes

- With different sizes you need to maintain more information
- *Need to pick the right instructions (movl vs movq, cmpl vs cmpq)*
- Should to allocate right amount of heap or stack space
- ▶ **Maintain size information in IRs!**
- It is a good idea to keep temp/registers of different sizes separate
- If you want moves from small to large temps then make conversion explicit

Disallow:

$$d^{64} \leftarrow s^{32}$$

Instead use:

$$d^{64} \leftarrow \text{zeroextend } s^{32}$$
$$d^{64} \leftarrow \text{signextend } s^{32}$$

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You could always use 8 bytes for spilling.

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Instead use:

$$\begin{aligned} d^{64} &\leftarrow \text{zeroextend } s^{32} \\ d^{64} &\leftarrow \text{signextend } s^{32} \end{aligned}$$