Script generated by TTT

Title: Seidl: Virtual_Machines (21.04.2015)

Date: Tue Apr 21 10:17:05 CEST 2015

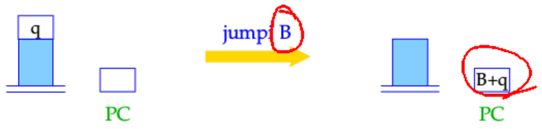
Duration: 88:06 min

Pages: 32

4.5 The switch-Statement

Idea:

- Multi-target branching in constant time!
- Use a jump table, which contains at its i-th position the jump to the beginning of the i-th alternative.
- Realized by indexed jumps.



PC = B + S[SP];
SP--;

Simplification:

We only regard **switch**-statements of the following form:

$$
\begin{array}{lll}
s & \equiv & \textbf{switch}\ (e)\ \{ \\
 & & \quad \textbf{case}\ 0\text{:}\ \ ss_0\ \textbf{break;} \\
 & & \quad \textbf{case}\ 1\text{:}\ \ ss_1\ \textbf{break;} \\
 & & \qquad \vdots \\
 & & \quad \textbf{case}\ k-1\text{:}\ \ ss_{k-1}\ \textbf{break;} \\
 & & \quad \textbf{default:}\ \ ss_k \\
 & & \}
\end{array}
$$

s is then translated into the instruction sequence:

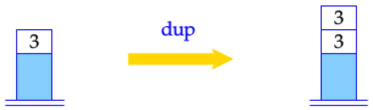
code s ρ	=	$\text{code}_R\ e\ \rho$	C_0:	code ss_0 ρ	B:	jump C_0
		check 0 k B		jump D		...
				...		jump C_k
			C_k:	code ss_k ρ	D:	...
				jump D		

- The Macro check 0 k B checks, whether the R-value of e is in the interval $[0, k]$, and executes an indexed jump into the table B
- The jump table contains direct jumps to the respective alternatives.
- At the end of each alternative is an unconditional jump out of the **switch**-statement.

```
check 0 k B  =  dup        dup           jumpi B
                loadc 0    loadc k   A:  pop
                geq        le            loadc k
                jumpz A    jumpz A       jumpi B
```

jump (B+2)

- The R-value of e is still needed for indexing after the comparison. It is therefore copied before the comparison.
- This is done by the instruction dup.
- The R-value of e is replaced by k before the indexed jump is executed if it is less than 0 or greater than k.



S[SP+1] = S[SP];
SP++;


```
check 0 k B  =  dup        dup           jumpi B
                loadc 0    loadc k   A:  pop
                geq        le            loadc k
                jumpz A    jumpz A       jumpi B
```

- The R-value of e is still needed for indexing after the comparison. It is therefore copied before the comparison.
- This is done by the instruction dup.
- The R-value of e is replaced by k before the indexed jump is executed if it is less than 0 or greater than k.

42

code $s\ \rho$ =	$\text{code}_R\ e\ \rho$	C_0:	code $ss_0\ \rho$	B:	jump C_0
	check 0 k B		jump D		...
			...		jump C_k
		C_k:	code $ss_k\ \rho$	D:	...
			jump D		

- The Macro check 0 k B checks, whether the R-value of e is in the interval $[0, k]$, and executes an indexed jump into the table B
- The jump table contains direct jumps to the respective alternatives.
- At the end of each alternative is an unconditional jump out of the **switch**-statement.

Note:

- The jump table could be placed directly after the code for the Macro check. This would save a few unconditional jumps. However, it may require to search the **switch**-statement twice.
- If the table starts with u instead of 0, we have to decrease the R-value of e by u before using it as an index.
- If all potential values of e are definitely in the interval $[0, k]$, the macro check is not needed.

Simplification:

We only regard **switch**-statements of the following form:

$$
\begin{array}{lll}
s & \equiv & \textbf{switch}\ (e)\ \{ \\
 & & \quad \textbf{case}\ 0\text{:}\quad ss_0\ \textbf{break;} \\
 & & \quad \textbf{case}\ 1\text{:}\quad ss_1\ \textbf{break;} \\
 & & \quad\quad \vdots \\
 & & \quad \textbf{case}\ k-1\text{:}\quad ss_{k-1}\ \textbf{break;} \\
 & & \quad \textbf{default:}\quad ss_k \\
 & & \}
\end{array}
$$

s is then translated into the instruction sequence:

check 0 k B	=	dup	dup		jumpi B
		loadc 0	loadc k	A:	pop
		geq	le		loadc k
		jumpz A	jumpz A		jumpi B

- The R-value of e is still needed for indexing after the comparison. It is therefore copied before the comparison.
- This is done by the instruction dup.
- The R-value of e is replaced by k before the indexed jump is executed if it is less than 0 or greater than k.

Note:

- The jump table could be placed directly after the code for the Macro check. This would save a few unconditional jumps. However, it may require to search the **switch**-statement twice.
- If the table starts with u instead of 0, we have to decrease the R-value of e by u before using it as an index.
- If all potential values of e are definitely in the interval $[0, k]$, the macro check is not needed.

5 Storage Allocation for Variables

Goal:

Associate statically, i.e. at compile time, with each variable x a fixed (relative) address $\rho\, x$

Assumptions:

- variables of basic types, e.g. **int**, ... occupy one storage cell.
- variables are allocated in the store in the order, in which they are declared, starting at address 1.

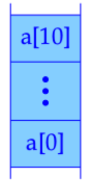
Consequently, we obtain for the declaration $d \equiv t_1\ x_1; \ldots\ t_k\ x_k;$ (t_i basic type) the address environment ρ such that

$$\rho\, x_i = i, \quad i = 1, \ldots, k$$

5.1 Arrays

Example **int** $[11]\ a;$

The array a consists of 11 components and therefore needs 11 cells.
$\rho\, a$ is the address of the component $a[0]$.



We need a function sizeof (notation: $|\cdot|$), computing the space requirement of a type:

$$|t| = \begin{cases} 1 & \text{if } t \text{ basic} \\ k \cdot |t'| & \text{if } t \equiv t'[k] \end{cases}$$

Accordingly, we obtain for the declaration $d \equiv t_1\ x_1; \ldots\ t_k\ x_k;$

$$\begin{array}{lcll} \rho\, x_1 & = & 1 & \\ \rho\, x_i & = & \rho\, x_{i-1} + |t_{i-1}| & \text{for } i > 1 \end{array}$$

Since $|\cdot|$ can be computed at compile time, also ρ can be computed at compile time.

Task:

Extend code_L and code_R to expressions with accesses to array components.

Be $t[c]\ a;$ the declaration of an array a.

To determine the start address of a component $a[i]$, we compute $\rho\, a + |t| * (\textit{R-value of } i)$.

In consequence:

$$\begin{array}{lcl} \text{code}_L\ a[e]\ \rho & = & \text{loadc}\ (\rho\, a) \\ & & \text{code}_R\ e\ \rho \\ & & \text{loadc}\ |t| \\ & & \text{mul} \\ & & \text{add} \end{array}$$

... or more general:

$$
\begin{aligned}
\text{code}_L\ e_1[e_2]\ \rho \quad = \quad & \text{code}_R\ e_1\ \rho \\
& \text{code}_R\ e_2\ \rho \\
& \text{loadc}\ |t| \\
& \text{mul} \\
& \text{add}
\end{aligned}
$$

Remark:

- In C, an array is a pointer. A declared array a is a pointer-constant, whose R-value is the start address of the array.
- Formally, we define for an array e: $\text{code}_R\ e\ \rho = \text{code}_L\ e\ \rho$
- In C, the following are equivalent (as L-values):

$$2[a] \qquad a[2] \qquad a+2$$

Normalization: Array names and expressions evaluating to arrays occur in front of index brackets, index expressions inside the index brackets.

a + 2

$$
\begin{aligned}
\text{code}_L\ e_1[e_2]\ \rho \quad = \quad & \text{code}_R\ e_1\ \rho \\
& \text{code}_R\ e_2\ \rho \\
& \text{loadc}\ |t| \\
& \text{mul} \\
& \text{add}
\end{aligned}
$$

Remark:

- In C, an array is a pointer. A declared array a is a pointer-constant, whose R-value is the start address of the array.
- Formally, we define for an array e: $\text{code}_R\ e\ \rho = \text{code}_L\ e\ \rho$
- In C, the following are equivalent (as L-values):

$$2[a] \qquad a[2] \qquad a+2$$

Normalization: Array names and expressions evaluating to arrays occur in front of index brackets, index expressions inside the index brackets.

5.2 Structures

In Modula and Pascal, structures are called Records.

Simplification:

Names of structure components are not used elsewhere.
Alternatively, one could manage a separate environment ρ_{st} for each structure type st.

Be **struct** { **int** a; **int** b; } x; part of a declaration list.

- x has as relative address the address of the first cell allocated for the structure.
- The components have addresses relative to the start address of the structure. In the example, these are $a \mapsto 0, b \mapsto 1$.

Let $t \equiv \textbf{struct}\,\{t_1\ c_1; \ldots t_k\ c_k;\}$. We have

$$
\begin{aligned}
|t| &= \sum_{i=1}^{k} |t_i| \\
\rho\, c_1 &= 0 \quad \text{and} \\
\rho\, c_i &= \rho\, c_{i-1} + |t_{i-1}| \quad \text{for } i > 1
\end{aligned}
$$

We thus obtain:

$$
\begin{aligned}
\text{code}_L\ (e.c)\ \rho \quad = \quad & \text{code}_L\ e\ \rho \\
& \text{loadc}\ (\rho\, c) \\
& \text{add}
\end{aligned}
$$

Example

Be **struct** { **int** a; **int** b; } x; such that $\rho = \{x \mapsto 13, a \mapsto 0, b \mapsto 1\}$.

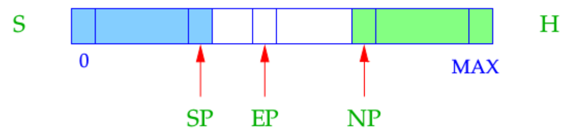
This yields:

$$\text{code}_L\ (x.b)\ \rho \quad = \quad \begin{array}{l}\text{loadc 13}\\ \text{loadc 1}\\ \text{add}\end{array}$$

6 Pointer and Dynamic Storage Management

Pointer allow the access to anonymous, dynamically generated objects, whose life time is not subject to the LIFO-principle.

$\Longrightarrow$ We need another potentially unbounded storage area H – the Heap.



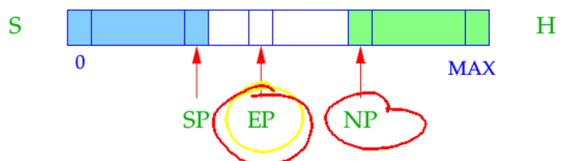
NP $\hat{=}$ New Pointer; points to the lowest occupied heap cell.

EP $\hat{=}$ Extreme Pointer; points to the uppermost cell, to which SP can point (during execution of the actual function).

6 Pointer and Dynamic Storage Management

Pointer allow the access to anonymous, dynamically generated objects, whose life time is not subject to the LIFO-principle.

$\Longrightarrow$ We need another potentially unbounded storage area H – the Heap.



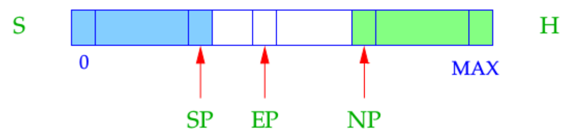
NP $\hat{=}$ New Pointer; points to the lowest occupied heap cell.

EP $\hat{=}$ Extreme Pointer; points to the uppermost cell, to which SP can point (during execution of the actual function).

6 Pointer and Dynamic Storage Management

Pointer allow the access to anonymous, dynamically generated objects, whose life time is not subject to the LIFO-principle.

$\Longrightarrow$ We need another potentially unbounded storage area H – the Heap.



NP $\hat{=}$ New Pointer; points to the lowest occupied heap cell.

EP $\hat{=}$ Extreme Pointer; points to the uppermost cell, to which SP can point (during execution of the actual function).

Idea:

- Stack and Heap grow toward each other in S, but must not collide. (Stack Overflow).
- A collision may be caused by an increment of SP or a decrement of NP.
- EP saves us the check for collision at the stack operations.
- The checks at heap allocations are still necessary.

What can we do with pointers (pointer values)?

- set a pointer to a storage cell,
- dereference a pointer, access the value in a storage cell pointed to by a pointer.

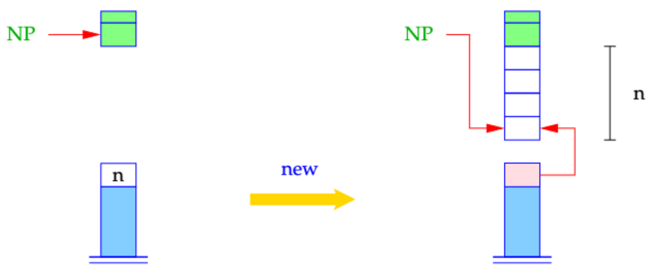
There a two ways to set a pointer:

(1) A call **malloc** (e) reserves a heap area of the size of the value of e and returns a pointer to this area:

$$\begin{array}{lcl} \text{code}_R\ \textbf{malloc}\ (e)\ \rho & = & \text{code}_R\ e\ \rho \\ & & \text{new} \end{array}$$

(2) The application of the address operator & to a variable returns a pointer to this variable, i.e. its address (≙ L-value). Therefore:

$$\text{code}_R\ (\&e)\ \rho = \text{code}_L\ e\ \rho$$




```
if (NP - S[SP] ≤ EP)
        S[SP] = NULL;
else {
        NP = NP - S[SP];
        S[SP] = NP;
}
```

- NULL is a special pointer constant, identified with the integer constant 0.
- In the case of a collision of stack and heap the NULL-pointer is returned.

What can we do with pointers (pointer values)?

- set a pointer to a storage cell,
- dereference a pointer, access the value in a storage cell pointed to by a pointer.

There a two ways to set a pointer:

(1) A call **malloc** (e) reserves a heap area of the size of the value of e and returns a pointer to this area:

$$\begin{array}{lcl} \text{code}_R\ \textbf{malloc}\ (e)\ \rho & = & \text{code}_R\ e\ \rho \\ & & \text{new} \end{array}$$

(2) The application of the address operator & to a variable returns a pointer to this variable, i.e. its address (≙ L-value). Therefore:

$$\text{code}_R\ (\&e)\ \rho = \text{code}_L\ e\ \rho$$

Dereferencing of Pointers:

The application of the operator $*$ to the expression e returns the contents of the storage cell, whose address is the R-value of e:

$$\text{code}_L\ (*e)\ \rho = \text{code}_R\ e\ \rho$$

Example Given the declarations

struct t { int $a[7]$; struct t $*b$; };
int i, j;
struct t $*pt$;

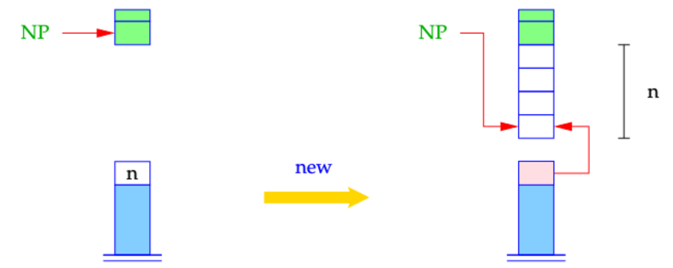
and the expression $((pt \to b) \to a)[i+1]$

Because of $e \to a \equiv (*e).a$ holds:

$$\text{code}_L\ (e \to a)\ \rho \quad = \quad \text{code}_R\ e\ \rho$$

loadc $(\rho\, a)$

add




```
if (NP - S[SP] ≤ EP)
        S[SP] = NULL;
else {
        NP = NP - S[SP];
        S[SP] = NP;
}
```

- NULL is a special pointer constant, identified with the integer constant 0.
- In the case of a collision of stack and heap the NULL-pointer is returned.

What can we do with pointers (pointer values)?

- set a pointer to a storage cell,
- dereference a pointer, access the value in a storage cell pointed to by a pointer.

There a two ways to set a pointer:

(1) A call **malloc** (e) reserves a heap area of the size of the value of e and returns a pointer to this area:

$$\text{code}_R\ \textbf{malloc}\ (e)\ \rho \quad = \quad \text{code}_R\ e\ \rho$$

new

(2) The application of the address operator & to a variable returns a pointer to this variable, i.e. its address ($\hat{=}$ L-value). Therefore:

$$\text{code}_R\ (\&e)\ \rho = \text{code}_L\ e\ \rho$$

Dereferencing of Pointers:

The application of the operator $*$ to the expression e returns the contents of the storage cell, whose address is the R-value of e:

$$\text{code}_L\ (*e)\ \rho = \text{code}_R\ e\ \rho$$

Example Given the declarations

struct t { int $a[7]$; struct t $*b$; };
int i, j;
struct t $*pt$;

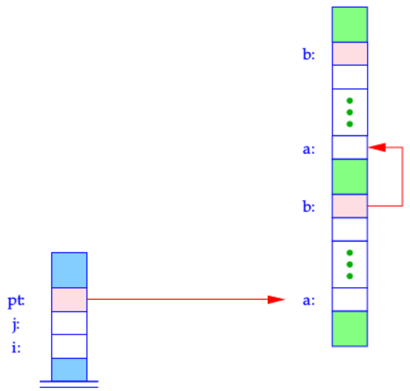
and the expression $((pt \to b) \to a)[i+1]$

Because of $e \to a \equiv (*e).a$ holds:

$$\text{code}_L\ (e \to a)\ \rho \quad = \quad \text{code}_R\ e\ \rho$$

loadc $(\rho\, a)$

add


b:
a:
b:
pt:
j:
i:
a: