How C differs from Java for Symbolic Program Execution

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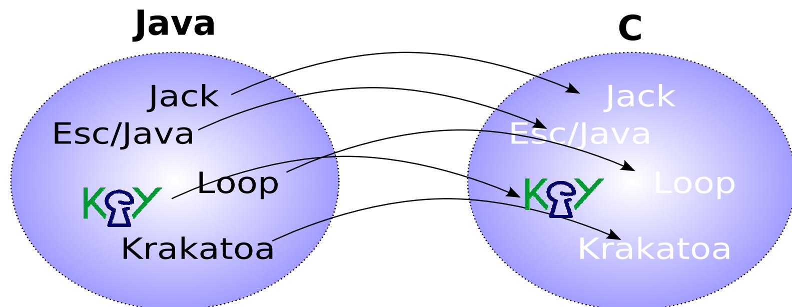
Motivation



KeY System

- Automatic and Interactive
- Verification System and Test Generator
- 100% JavaCard

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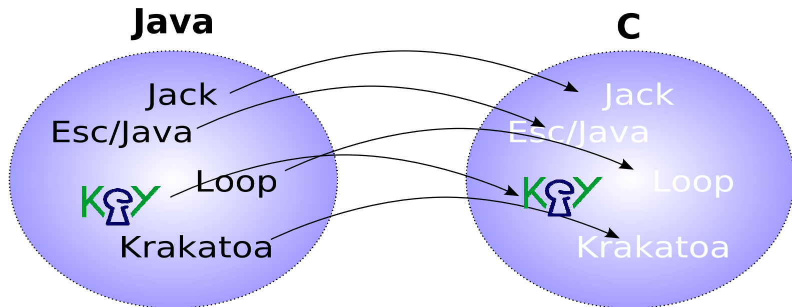

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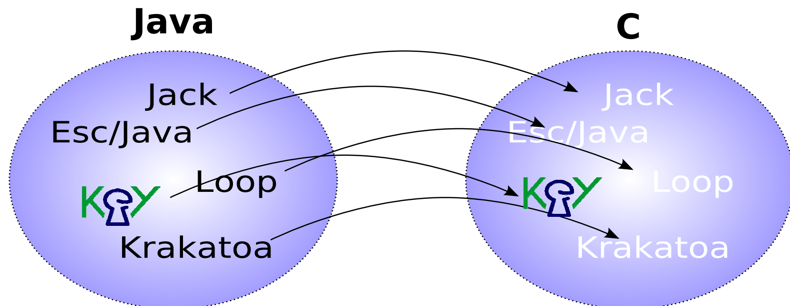

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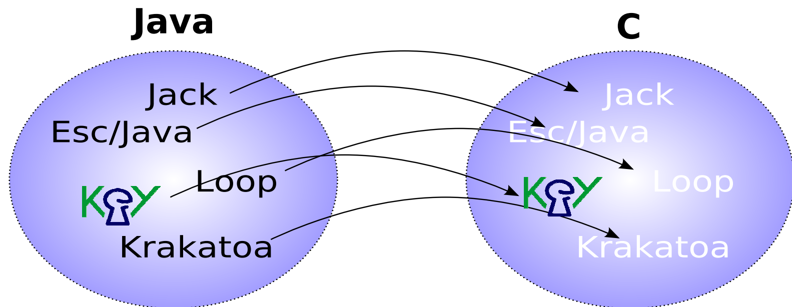

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Equivalent

C	$\longleftrightarrow$	Java
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a= &b		a=m() //m() throws Ex
range(int)	$\neq$	range(int)

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Differences Overview

- reference and dereference operators (ANSI C, MISRA C, C0)
- assignment of structures (ANSI C, MISRA C, C0)
- evaluation order of expressions and function arguments (ANSI C only)
- explicit object deallocation (ANSI C only)
- unions, pointer arithmetics, and type casts (ANSI C only)
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ANSI C

The Specification of ANSI C ...

- ...gives room for interpretation and customization of a C implementation.
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MISRA C

- Restrictions on the construction of expressions (evaluation order, types)
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- Single point of exist at the end of the function
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- No side effects in expression, no ambiguities of evaluation
- Size of arrays is staticaly fixed
- No pointers to local memories
- Two's complement representation
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Dynamic Logic - Details

Program-modal-operators + FOL = DL

$\langle \texttt{p} \rangle \phi \qquad \{a := b..\}\phi$

Program Variable = non-rigid Function Symbol

$$(prog.var.)\ \texttt{a} = a \text{ (logic const.)}$$
$$\texttt{o.a} = a(o)$$

Updates

$$\langle \texttt{o.a = t;} \rangle \phi \rightsquigarrow \{a(o) := t\}\phi$$
$$\langle \texttt{o.a = t;u.b = s} \rangle \phi \rightsquigarrow \{a(o) := t \,||\, b(u') := s'\}\phi$$

Replace $\langle \texttt{prog} \rangle \phi$ **by** $\{upd\}\phi$

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Reference and Dereference Operators (ANSI C, MISRA C, C0)

Indirect access

- $\langle$`p=&a; *p=1;`$\rangle a = 1$
- $\{*(p) := a\}\{*(*(p)) := 1\} * (a) = 1$

Leverage program variables to object level

- a Pointer to the program variable "a"
- $* : Pointer \rightarrow Value$

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Step 1: Expression to Pointer

$$\begin{aligned}
\text{etp}(\mathsf{a}) &\leadsto \mathsf{a} \\
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Assignment of Structs (ANSI C, MISRA C, C0)

a,b∈C struct	a,b∈C struct**pointer**	a,b∈Java class

`b.m = d;`
`a = b;`
`b.m = e;`
	`b->m = d;`
	`a = b;`
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$a.m =^{\cdot} d$	`a->m` $=^{\cdot} e$	$a.m =^{\cdot} e$

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struct S {
int a,b,c,d,e;
int n[];
int m[100];
}s1,s2;
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Evaluation order of Expressions and Function Arguments (ANSI C only)

Example

$\langle$`i = 1; i = 2* ++i + 3*i;`$\rangle i = 7$

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Rule

Replace $\langle$`stmt(expr_1,..,expr_n);`$\rangle$ **by**
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unions, pointer arithmetics, and type casts (ANSI C only)

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union U {
  struct S1{
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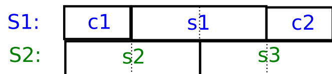


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char c= -1;
short a= *((short*)&c);
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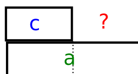


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int* p=&a;
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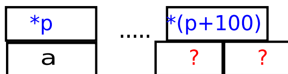

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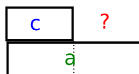


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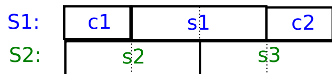

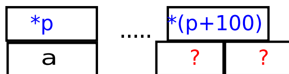

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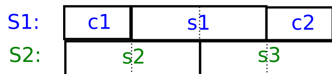


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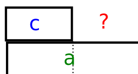
char c= -1;
short a= *((short*)&c);
```




```
int* p=&a;
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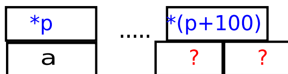
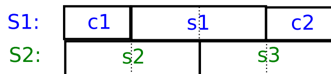


unions, pointer arithmetics, and type casts (ANSI C only)

```
union U {
  struct S1{
    unsigned char c1;
    unsigned short s1;
    unsigned char c2;
  }s1;
  struct S2{
    unsigned short s2;
    unsigned short s3;
  }s2;
};
```

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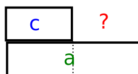


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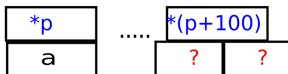

Explicit object deallocation (ANSI C only)

Example Dangling Pointers

```
int* pi= (int*) malloc (sizeof(int));
free(pi);
*pi=52; //access unallocated memory
```

Symbolically Executing Allocation in Java

Replace $\langle$`a = new T();`$\rangle$ **by**

$$\{a := \mathrm{obj}_T(next_T) \| \mathrm{next}_T := \mathrm{next}_T + 1\}$$

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Symbolically Executing Allocation in C

Replace ⟨`a = (*T)malloc(sizeof(T));`⟩ **by**

$$\{^*(a) := obj_T(next_T) \|^{cr} (^*(a)) := \mathsf{true} \| next_T := next_T + 1\}$$

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Replace ⟨`free(a);`⟩ **by** $\{^{cr}(^*(a)) := \mathit{false}\}$

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int a; free(&a);
struct S* s; ... ; free(&(s->m))
```

Extending the Type System

$$
\begin{array}{rcl}
obj_T(n) & : & \text{Root} \\
{}^{.m}(x),\ {}^{[]}(x,i) & : & \text{NonRoot } \textit{where } x \in \text{Root} \cup \text{NonRoot} \\
a,\ {}^{.m}(a),\ {}^{[]}(a,i) & : & \text{Static}
\end{array}
$$

Quantification

$\forall o : T_1.\Phi(o)$

$\forall i.\forall o : T_1.\left((i < \text{next}_T \wedge o = \text{obj}_T(i)) \rightarrow \Phi(o)\right)$

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$\forall i . \forall o : T_1 . ((i < \text{next}_T \wedge o = \text{obj}_T(i)) \rightarrow \Phi(o))$

goto-Statement (ANSI C only)

Example

```
int i;
for(i=0;i<2;i++)
{
   label1:
   printf("(i=%i) ",i);
}
if(i<4)goto label1;
```

Border Issues

Volatile program variables

- Prevents certain optimizations by an optimizing compiler
- Can be modified by external concurrently running programs

Function pointers

- An obtained function pointer must be “specified”
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