Low-Level Intermediate Representation

Compilers course

Masters in Informatics and Computing Engineering (MIEIC), 3rd Year

U.PORTO

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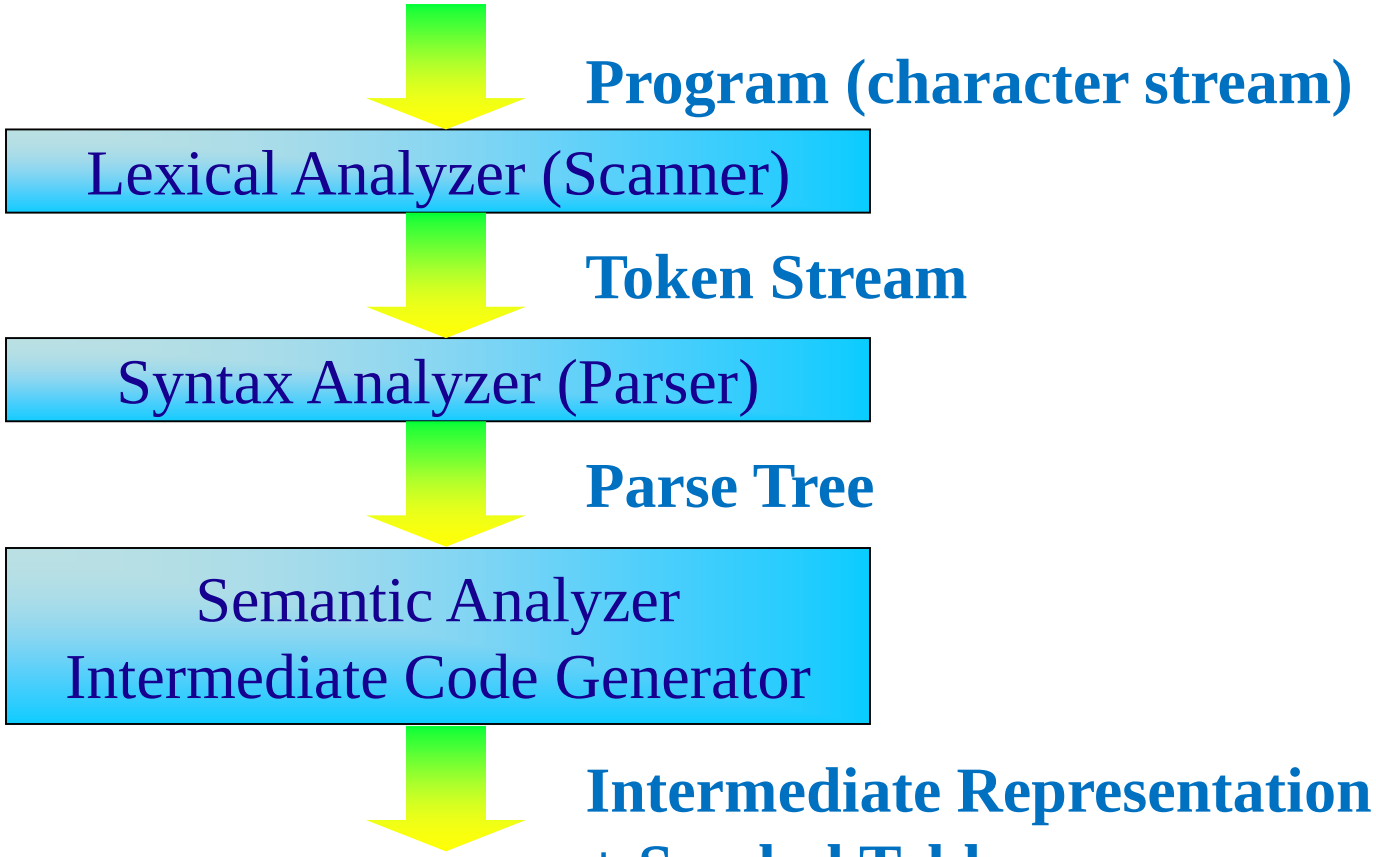
Compiler Stages



Most slides based on the Martin Rinard's MIT course

Conversion to Low-Level IR

- Convert structured control flow into control flow based on jumps (non-structured)
  - Conditional and inconditional branches
- Convert structured memory model into flat memory model
  - Flat addressing for variables
  - Flat addressing for arrays
- Continues independent of the machine language, but:
  - Movement to very close to the machine, to a standard machine models (flat space address, jumps)

Program Representations

- *Control Flow Graph* (CFG) where:
  - Nodes of the CFG are nodes of instructions
    - stl, sta, cbr, ldl, lda, ldp are nodes of instructions
    - +, *, <, ... are nodes of expressions
  - Edges in the CFG represent control flow
  - *Forks* in conditional branches
    - Represent two or more possible paths
  - *Merges* when the control can reach a point through multiple paths
  - An entry node and an exit node

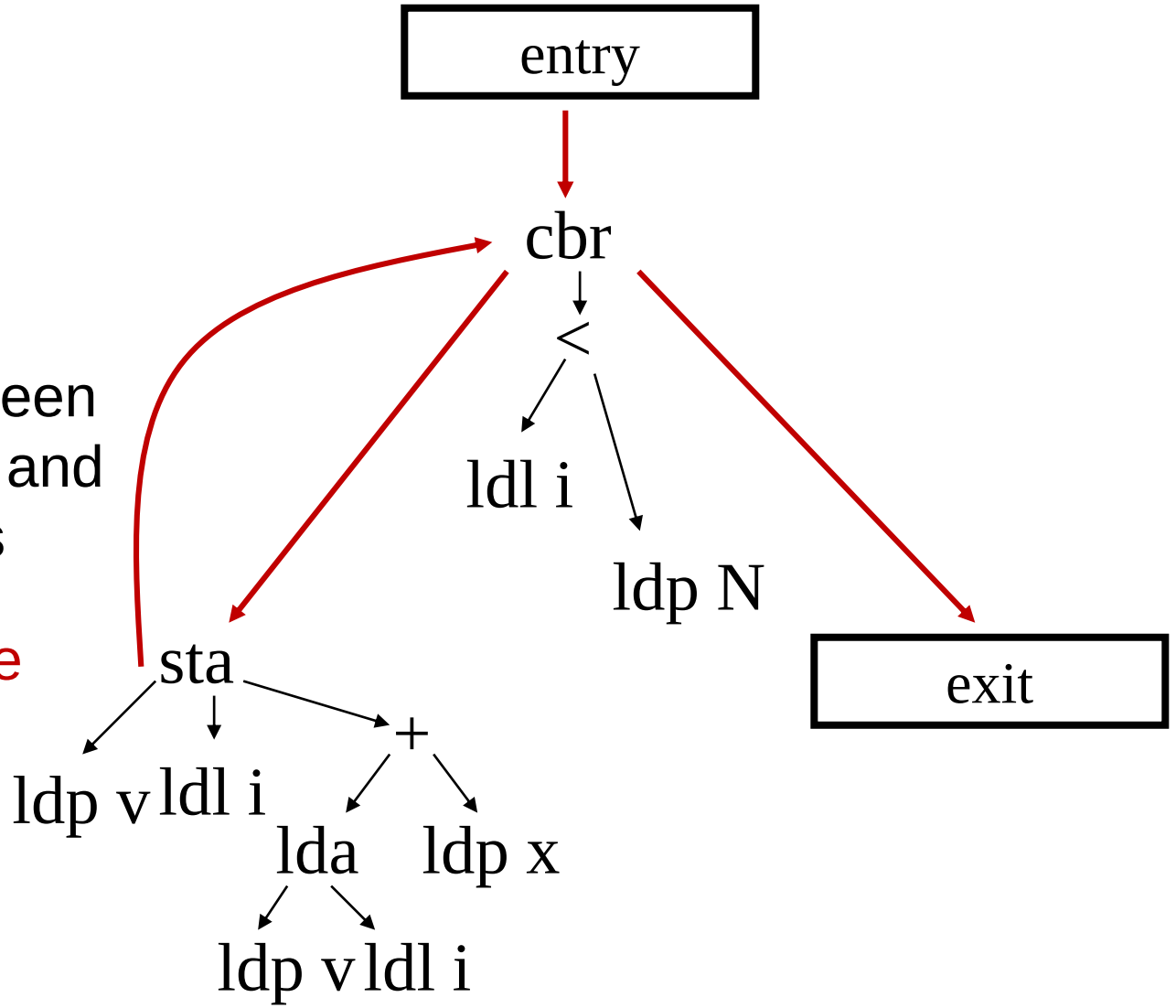
Note that there are other uses of CFGs, at higher-levels, with nodes representing basic blocks, etc.

Example: CFG

```
while (i < N)
   v[i] = v[i]+x;
```

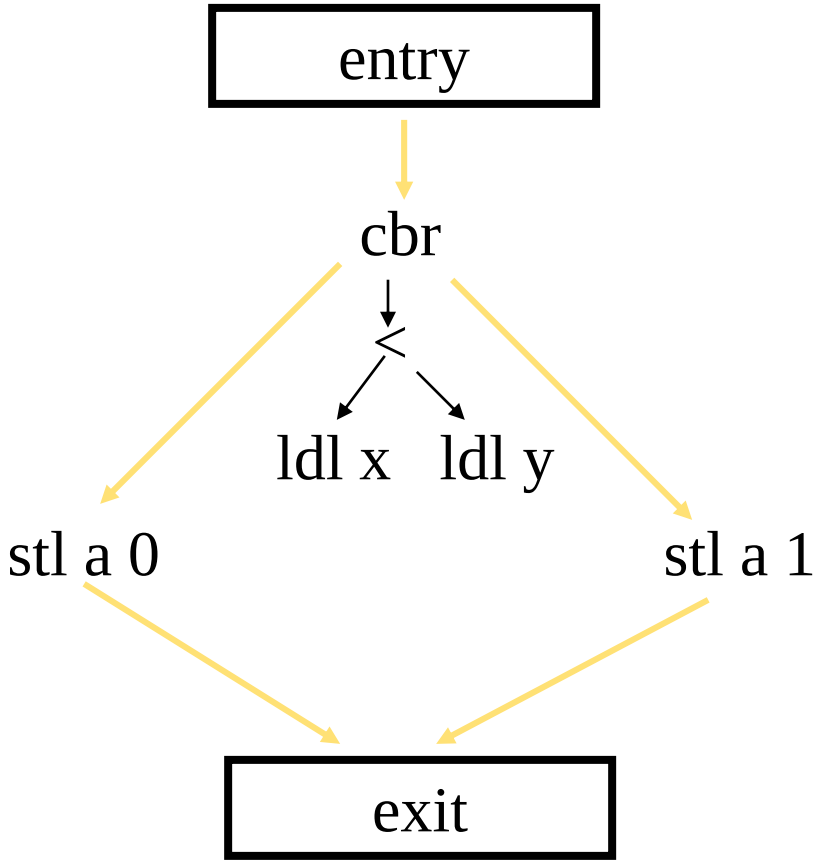
Edges between instructions and expressions

Edges of the control flow



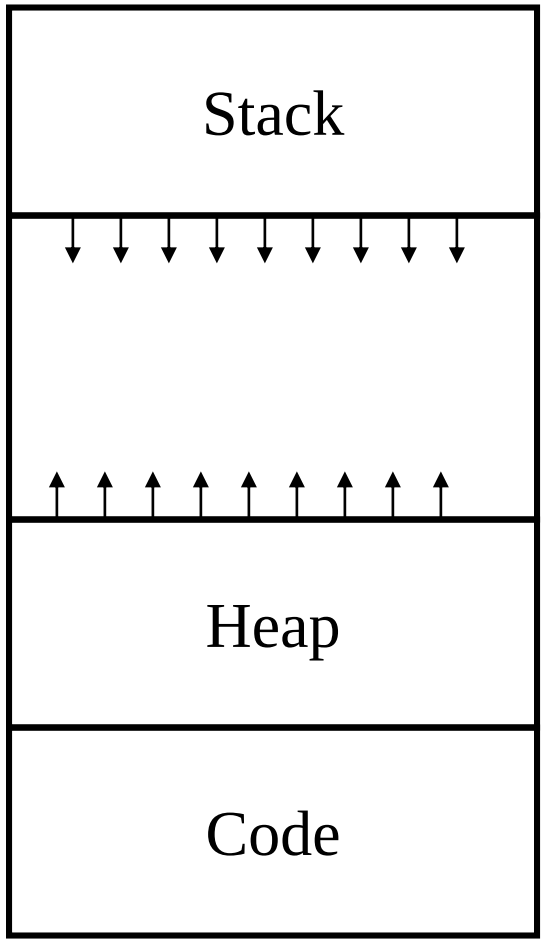
Example: CFG

```
if (x < y) {
    a = 0;
} else {
    a = 1;
}
```



Memory Model of the Target Machine

- A flat memory
  - Composed by words
  - Byte addressable
- Nodes model Load and Store instructions
  - ld addr,offset – result is the value in the memory position: addr+offset
  - st addr, offset, valor – write value in the memory position: addr+offset
  - Substitute nodes lda and ldl by ld nodes
  - Substitute nodes sta and stl by st nodes

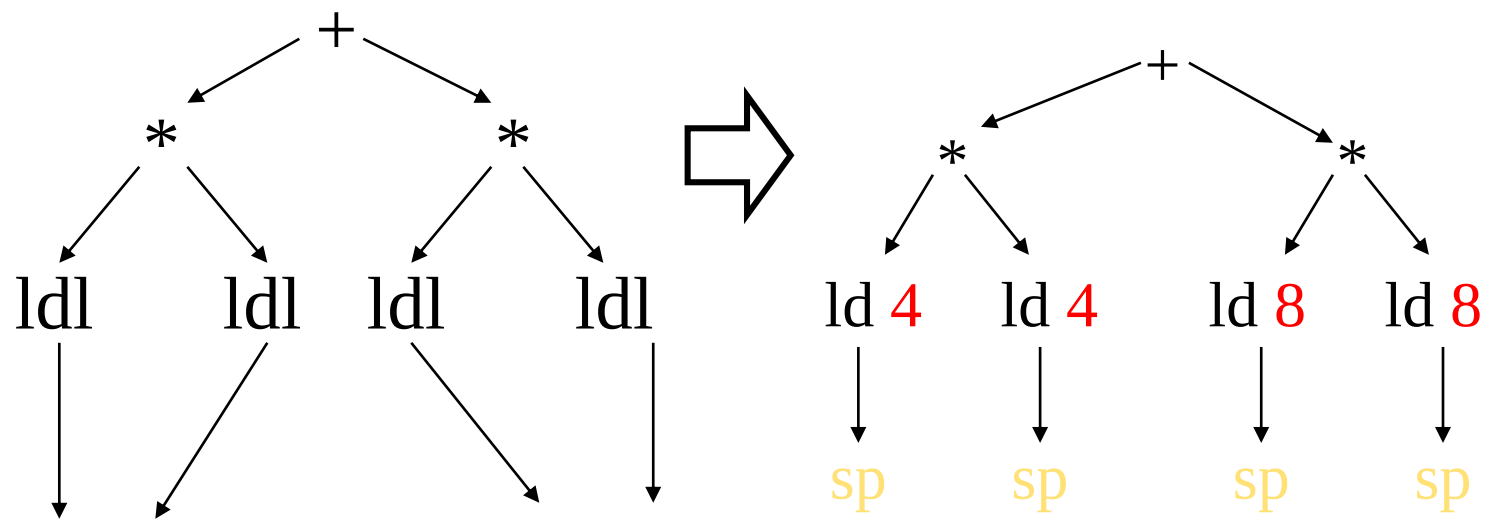


locals (some parameters)

Arrays

Example:

- ld address offset
  - MEM[address+offset]
  - In the case of offset=4 relative to sp (MEM[$sp+offset]):
- x*x+y*y



Local descriptor for x (4) Local descriptor for y (8)

Parameters

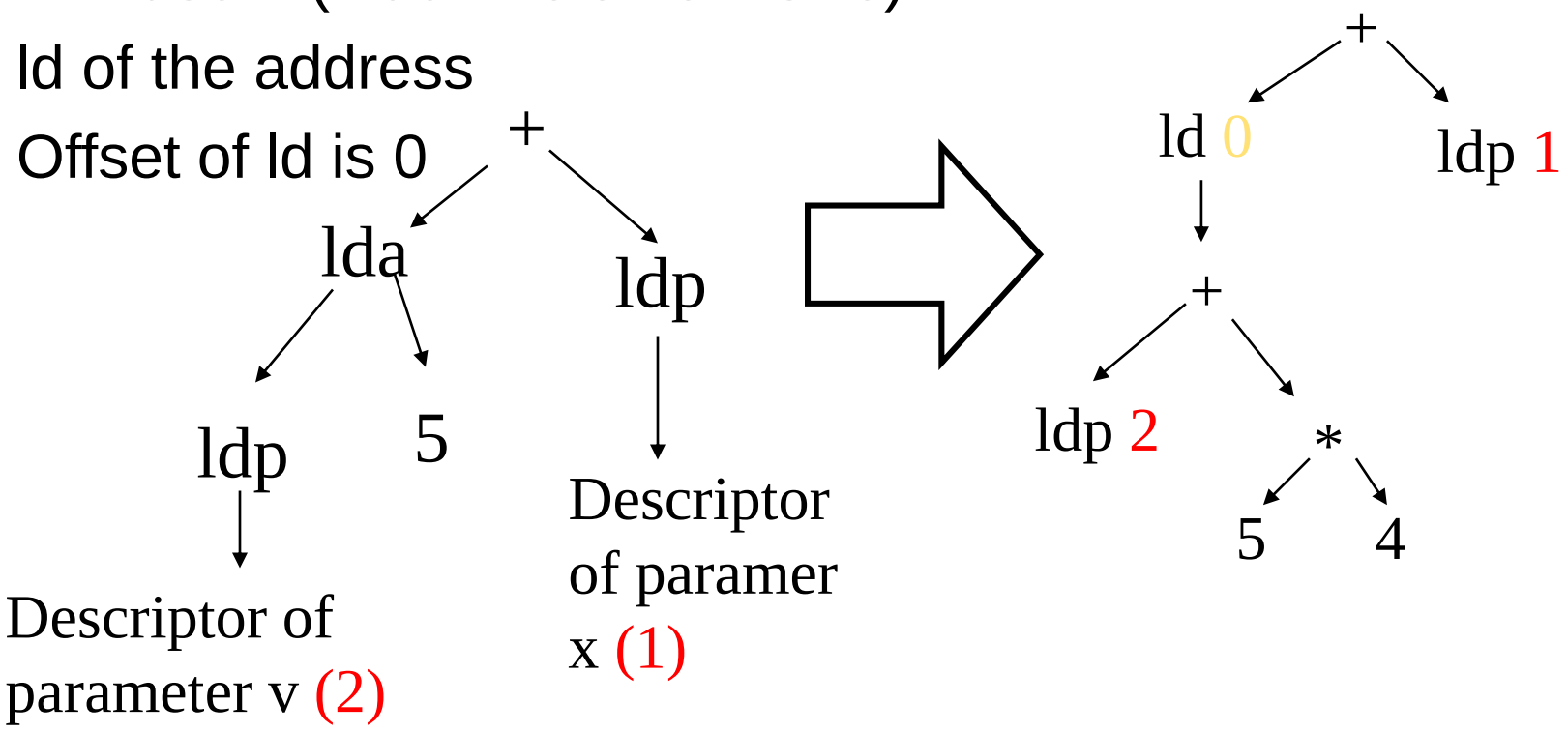
- Many processors have conventions in the calls
  - First parameter in register 5, second parameter in register 6, …
  - See $a0, $a1, … in MIPS
- Conventions vary with the machine
- Let's assume that each parameter is a word
- Let's address the parameters by the number
  - ldp <number of parameter>

Access to Array Elements

- Assume that the variable points to the first element of tha array
- Array elements stored in contiguous memory positions
- What is the address of v[5]?
  - v is an array of integers: assume integers of 4 bytes
  - (addres of v) + (5*4)
- Address calculation
  - Base of Array + (index * element size)

Example: v[5]+x

- Conversion of lda nodes to ld nodes
- Calculate address
  - Base + (index * element size)
- ld of the address
- Offset of ld is 0



Local Variables

- Assume they are stored in the call stack
  - Address calculated using the offset from the stack pointer
- Remember:
  - Stack grows down and thus the offsets are positive numbers
  - Special symbol sp contains pointer to the stack

Actions in Function Calls (remember)

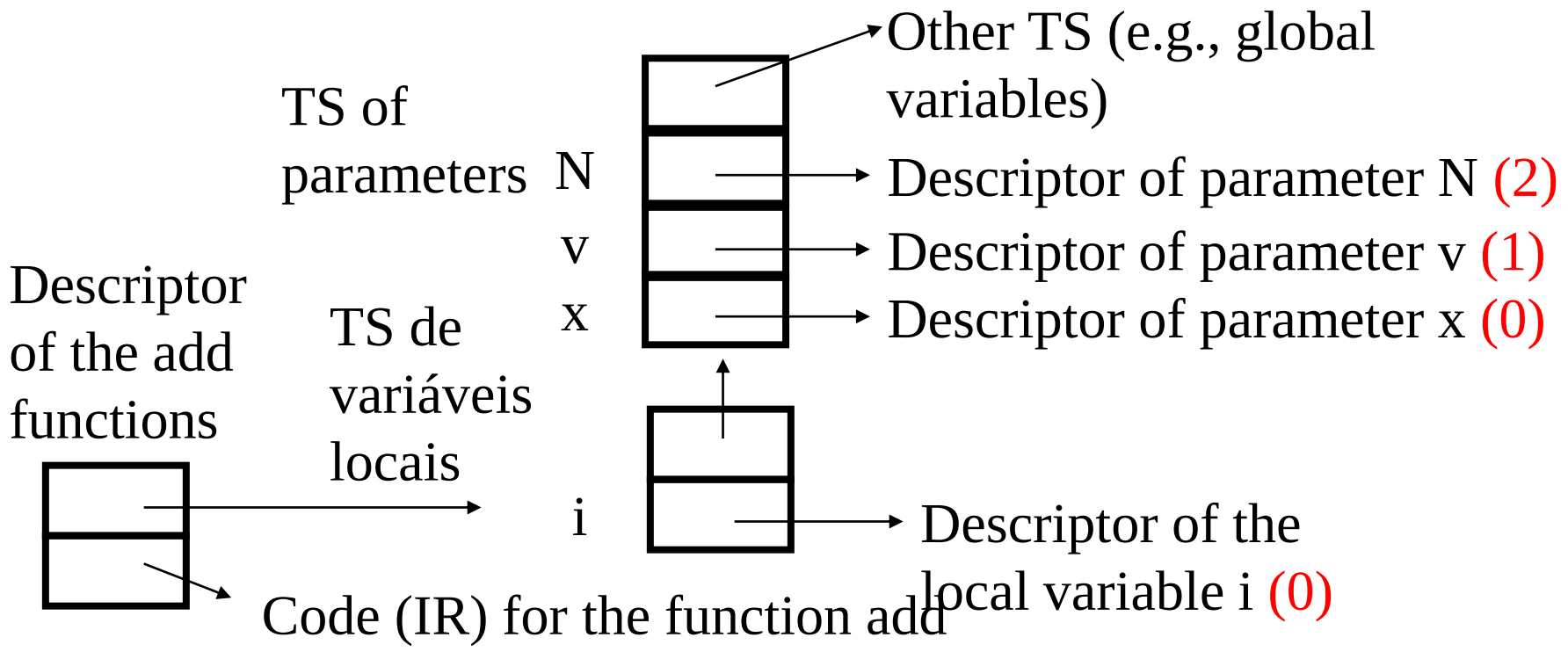
- Caller
  - Define parameters according to the convention on calls
  - Define return address using the calling convention
  - Branch to callee function
- Callee
  - Allocate stack frame = move (down) the stack pointer (sp)
  - Define return value according to the calling convention
  - Free stack frame = move (up) the stak pointer (sp)
  - Return to caller function

Management of the Stack (remember)

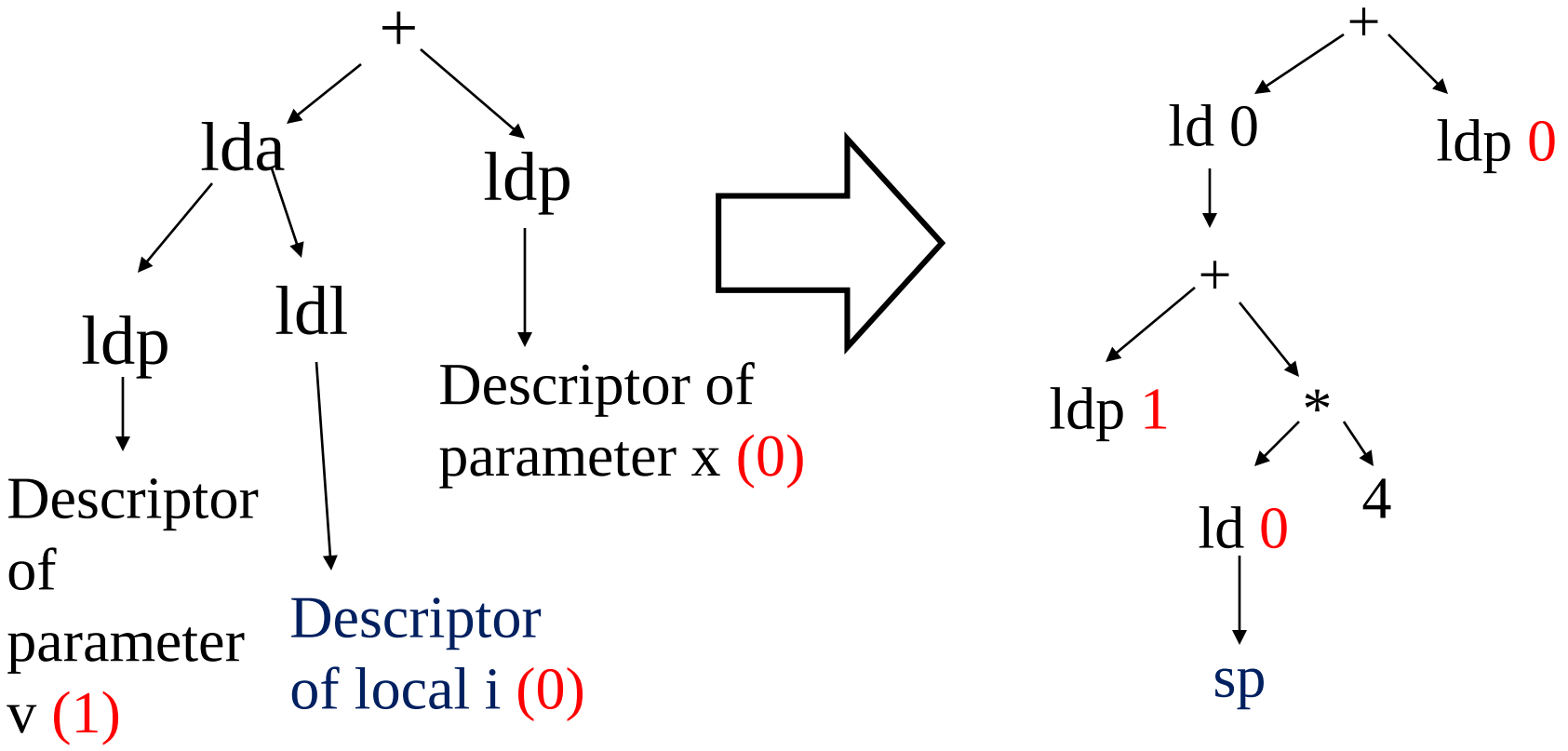
- Determine stack frame size
  - Allocate when the execution enters in the function
  - Free before returning from the function
  - Store all local variables
  - Additional space for parameters (when these surpass the number of registers assigned by convention for the arguments of the function)
- Define offsets for the local variables and parameters stored in the stack
  - Stored in the symbol tables (descriptors) of the locals and of the parameters
  - Continues to use ldp nodes to access to parameters

Elimination of ldl Nodes

- Use of *offsets* in the symbol table of locals and sp
- Replace *ldl* nodes by *ld* nodes
- Example of offsets for locals and parameters

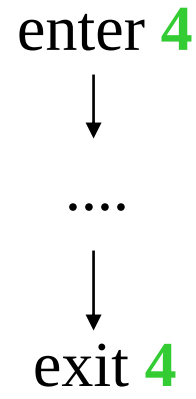


Example: v[i]+x


+
lda
ldp
ldp
ldl
Descriptor of parameter x (0)
Descriptor of parameter v (1)
Descriptor of local i (0)
+
ld 0
ldp 0
+
ldp 1
*
4
ld 0
sp

Enter and Exit Nodes: add function

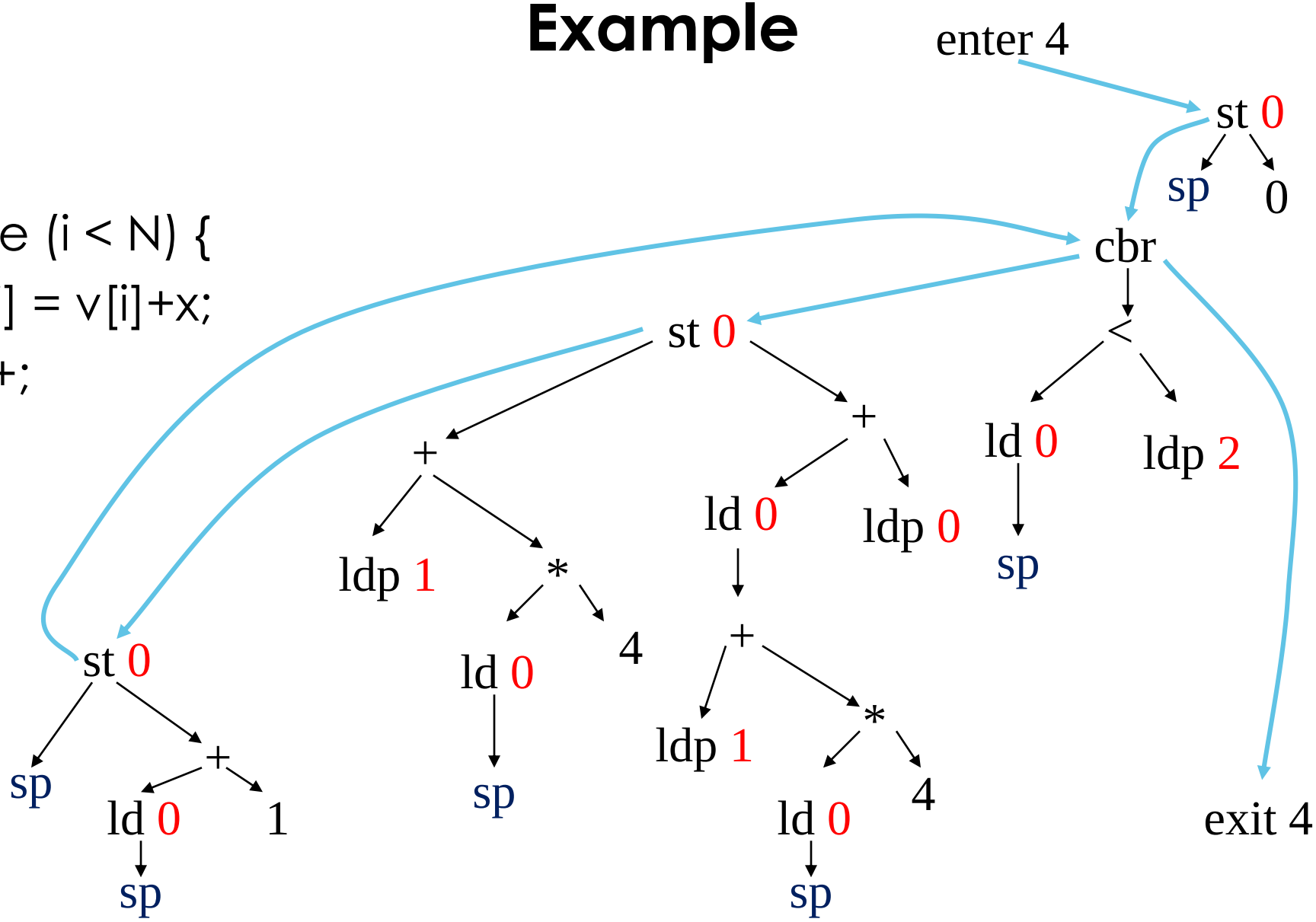
```
void add(int x, int[] v, int N) {
   int i;
   …
}
```



- Stack size for add function?
  - **4 bytes (space for i)**
    - Assuming 4 bytes for int
    - Assuming function paramerters in registers to pass arguments
- Enter and exit nodes are anotated with the size of the stack needed for the function

Example

```
i=0;
while (i < N) {
   v[i] = v[i]+x;
   i++;
}
```



Summary of the Low-Level IR

- Array accesses translated to *ld* or *st* nodes
  - Address is the base address of the array + index * element size
- Local accesses translated to *ld* or *st* nodes
  - Address in *sp*, offset is local offset
- Access to parameters is translated to:
  - Instructions *lpd* – specify number of the parameter
- Nodes Enter and Exit of a function identify stack size used by the function

Summary

- Translation of high-level IR to low-level IR
  - Flat address space
  - Elimination of the structured control flow, substituition by conditional and unconditional branches
- Moving toward the target machine