Structured Programming – Control Structures

Computer Engineering 1

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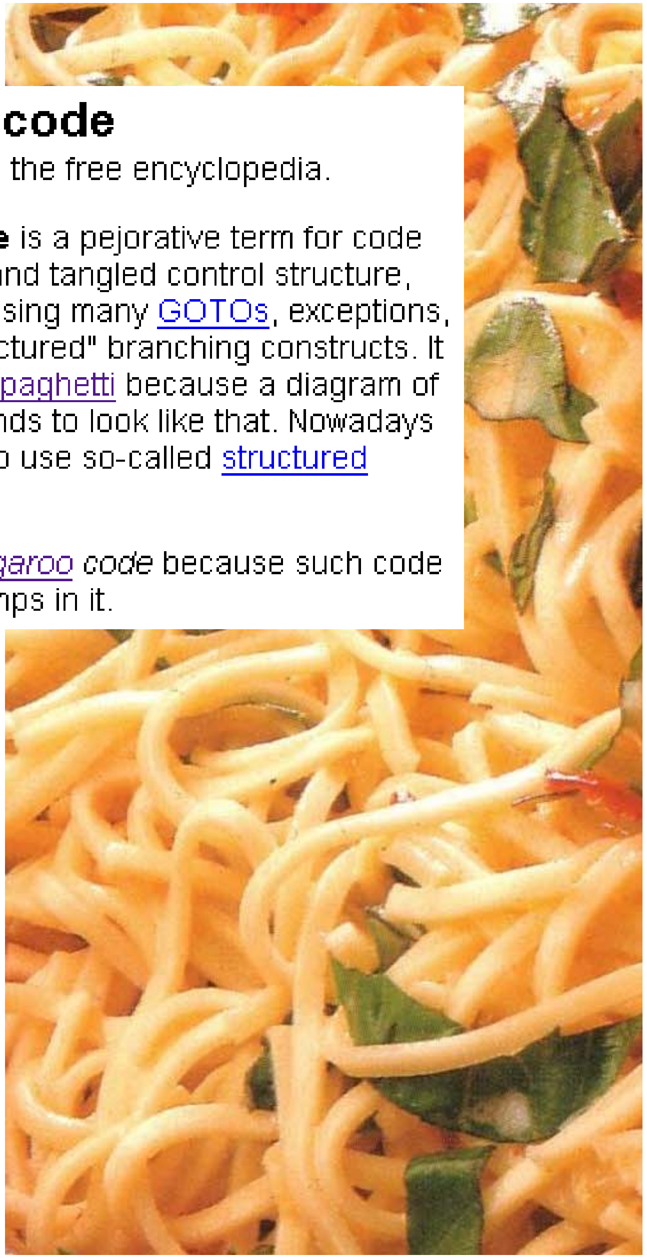
Motivation



Spaghetti code

From Wikipedia, the free encyclopedia.

Spaghetti code is a pejorative term for code with a complex and tangled control structure, especially one using many GOTOs, exceptions, or other "unstructured" branching constructs. It is named after spaghetti because a diagram of program flow tends to look like that. Nowadays it is preferable to use so-called structured programming.

Also called *kangaroo code* because such code has so many jumps in it.

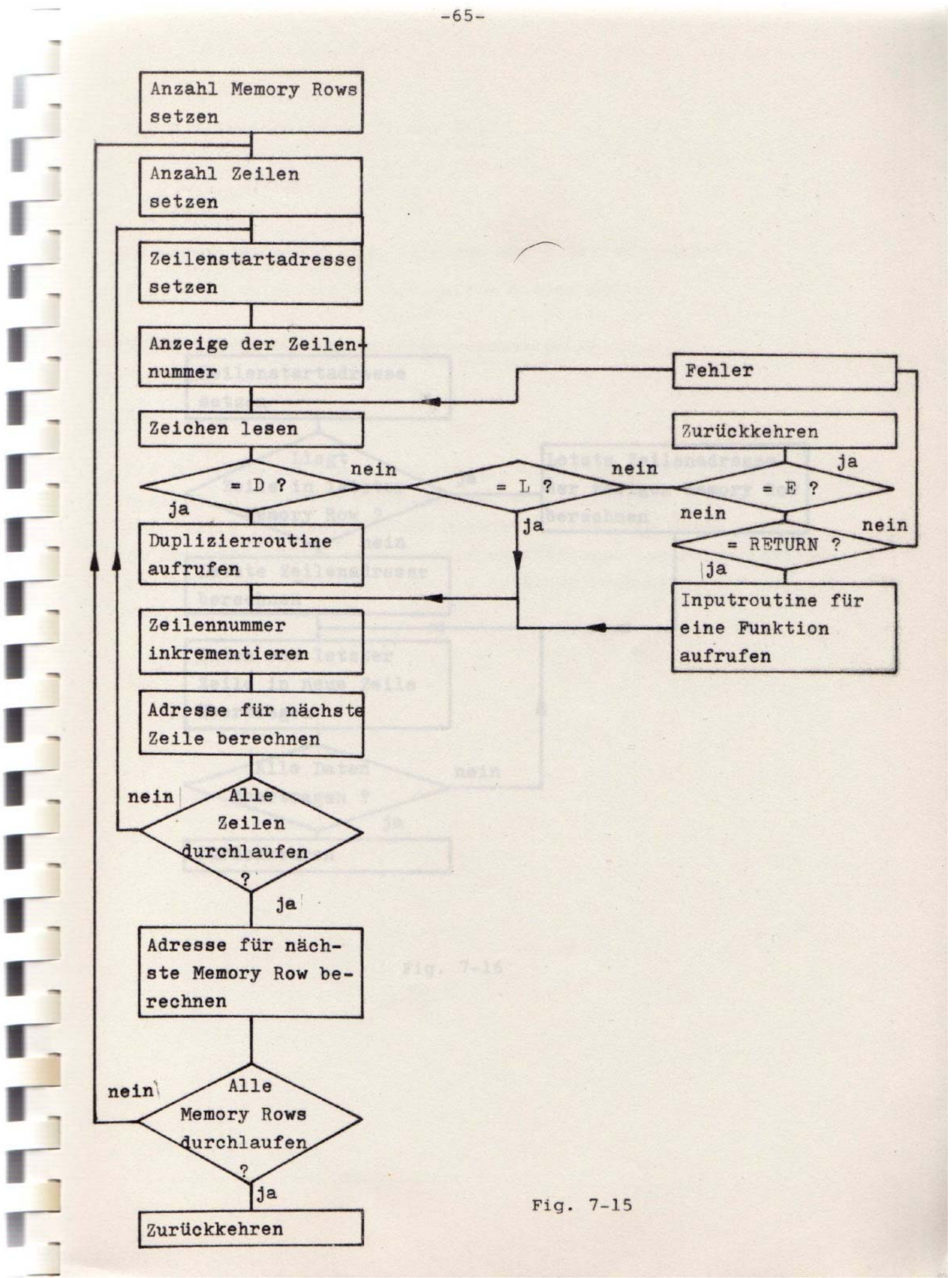

-65-
Anzahl Memory Rows setzen
Anzahl Zeilen setzen
Zeilenstartadresse setzen
Anzeige der Zeilennummer
Zeichen lesen
= D ?
nein
ja
Duplizierroutine aufrufen
= L ?
nein
ja
Fehler
Zurückkehren
ja
= E ?
nein
= RETURN ?
nein
ja
Inputroutine für eine Funktion aufrufen
Zeilennummer inkrementieren
Adresse für nächste Zeile berechnen
nein
Alle Zeilen durchlaufen ?
ja
Adresse für nächste Memory Row berechnen
nein
Alle Memory Rows durchlaufen ?
ja
Zurückkehren

Fig. 7-15

Agenda

- **Structured Programming**
- **Selection**
  - if – then - else
- **Loops**
  - Do – While
  - While
  - For
- **Switch Statements**

Learning Objectives

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At the end of this lesson you will be able

- to explain the basic concepts of structured programming
- to enumerate and explain the basic elements of a structogram
- to comprehend how a C-compiler implements control structures in assembly language
    - if-then-else
    - do-while loops
    - while loops
    - for loops
    - switch statements
- to program basic structograms in assembly language

Why Structured Programming ?

- **Rules for the structure of a program**
  - Patterns for control structures
    - Sequence
    - Selection   if - then - else
    - Iteration / Loop   for, while, do - while
  - Compilers generate code-blocks based on these patterns

- **Supports program development**
  - Clarity
  - Documentation
  - Maintenance
  - Allows to program on a higher level of abstraction

Structured Programming

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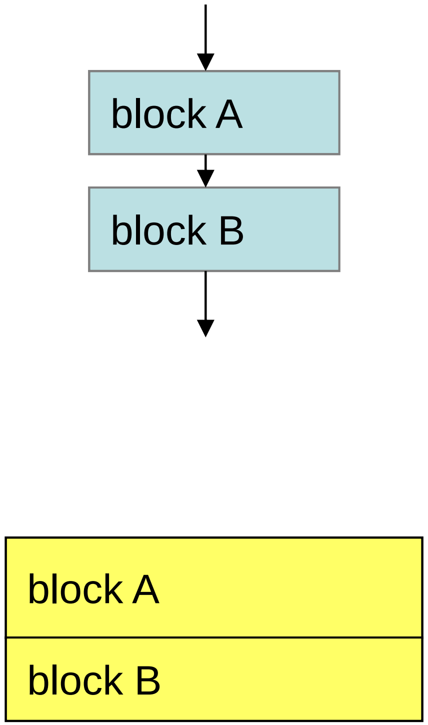
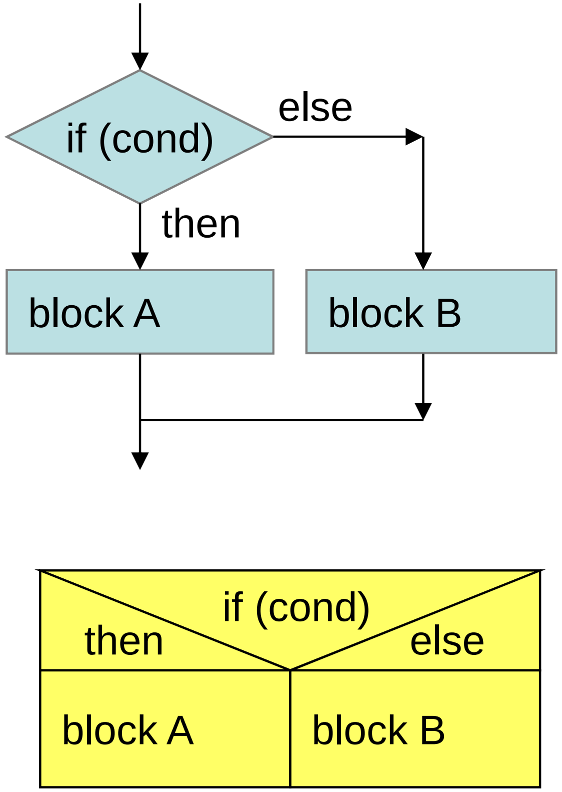
- **Program flow can be represented with three elements**

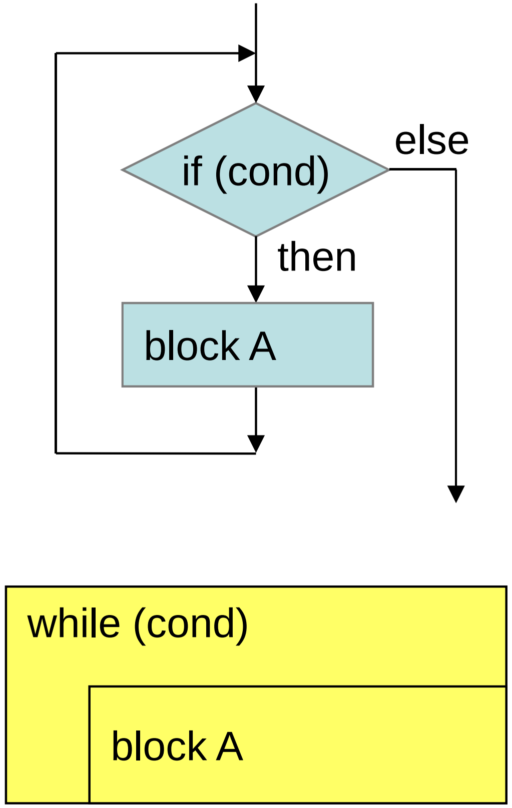
Sequence


block A
block B
block A
block B

Selection


if (cond)
else
then
block A
block B
if (cond)
then
else
block A
block B

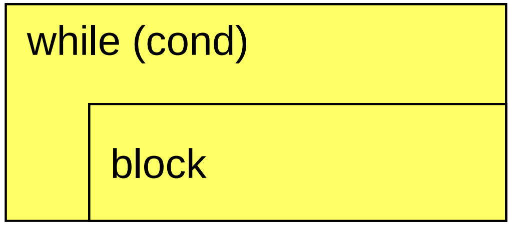
Iteration / loop


if (cond)
else
then
block A
while (cond)
block A

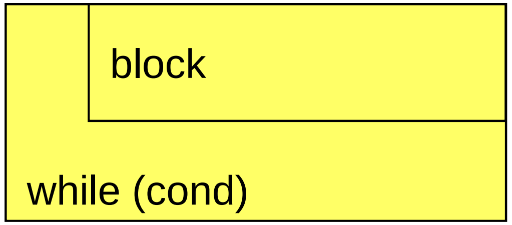
Further Structograms

Iteration

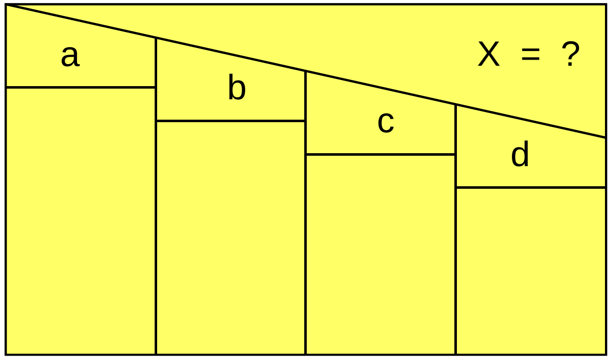
pre-test loop



post-test loop



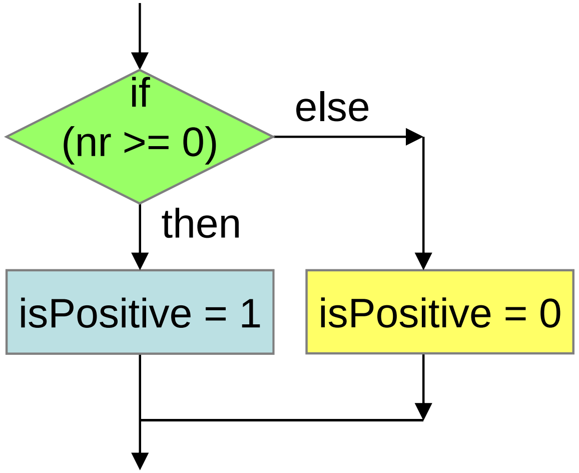
Switch statement (case)

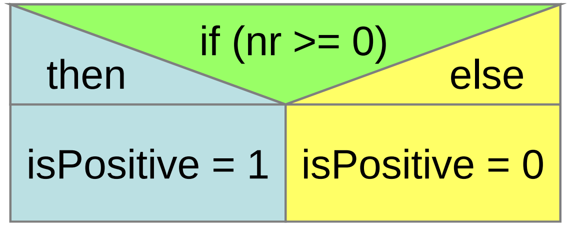


Selection

- **if(…) – then - else**

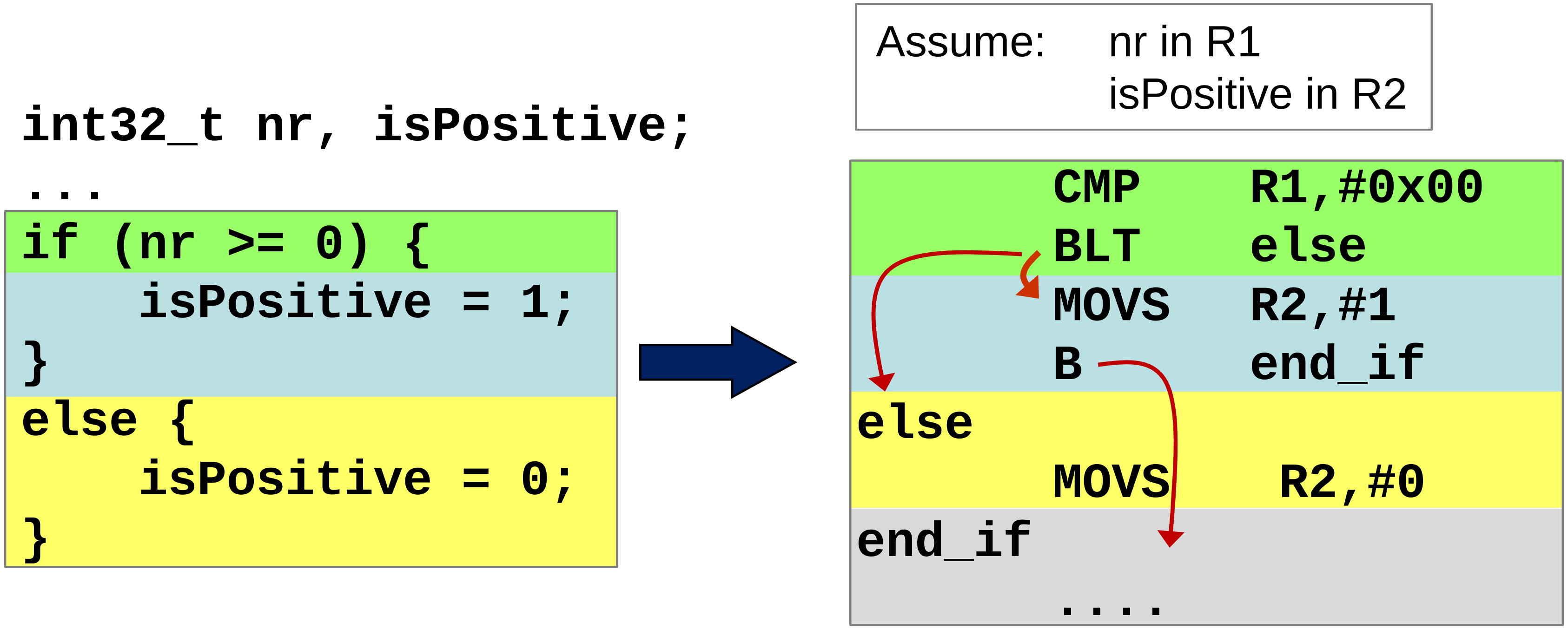
```
int32_t nr, isPositive;
...
if (nr >= 0) {
    isPositive = 1;
}
else {
    isPositive = 0;
}
```





Selection: if – then – else

- Compiler translates selection into assembly code
  - uses conditional and unconditional jumps



```
int32_t nr, isPositive;
...
if (nr >= 0) {
    isPositive = 1;
}
else {
    isPositive = 0;
}
```

Assume: nr in R1
isPositive in R2

```
        CMP     R1,#0x00
        BLT     else
        MOVS    R2,#1
        B       end_if
else
        MOVS     R2,#0
end_if
        ....
```

Selection: if – then – else

- Compiler takes the following approach
  - Rewrite using goto

```
if (test-expr)
      then-block
else
      else-block
```

not

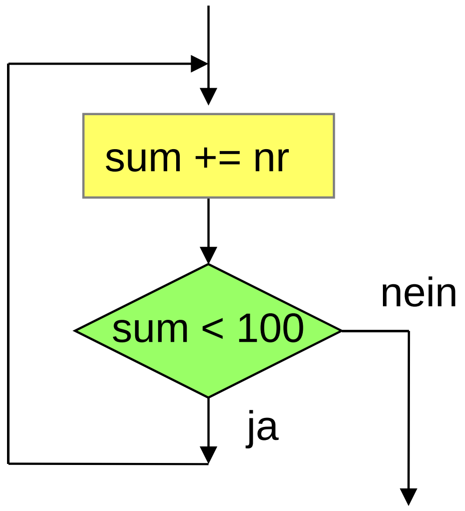
```
            if (!test-expr)
                  goto false;
            then-block
            goto done;
false:
            else-block
done:
```

```
if (nr >= 0) {
      isPositive = 1;
}
else {
      isPositive = 0;
}
```

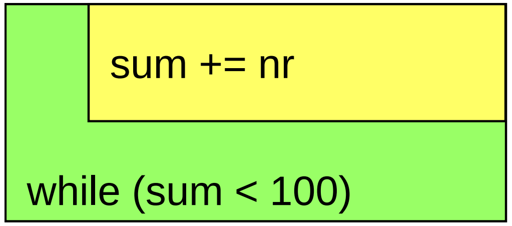
```
            CMP    R1,#0x00
            BLT    false
            MOVS   R2,#1
            B      done
false
            MOVS   R2,#0
done
```

Loops: Do-While Loops

```
int32_t nr, sum;
...
sum = 0;
do {
    sum += nr;
} while (sum < 100);
```



post-test loop



Loops: Do-While Loops

- Compiler translates loop to assembly code

```
int32_t nr, sum;
...
sum = 0;
do {
    sum += nr;
} while (sum < 100);
```

Assume: nr in R1
sum in R2

```
        MOVS    R2,#0
loop    ADDS    R2,R2,R1
        CMP     R2,#100
        BLT     loop
        ....
```

Loops: Do-While Loops

- Compiler takes the following approach
  - Rewrite using goto

```
do
      body-block
while (test-expr);
```

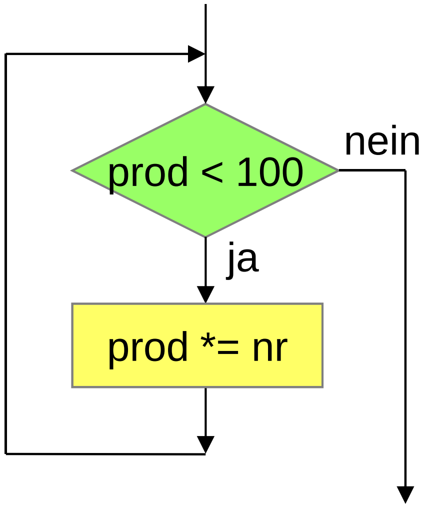
```
loop:
           body-block
           if (test-expr)
                 goto loop;
           ....
```

```
do {
      sum += nr;
} while (sum < 100);
```

```
loop
           ADDS   R2,R2,R1
           CMP    R2,#100
           BLT    loop
           ....
```

Loops: While Loops

```
int32_t nr, prod;
...
prod = 1;
while (prod < 100) {
    prod *= nr;
}
```

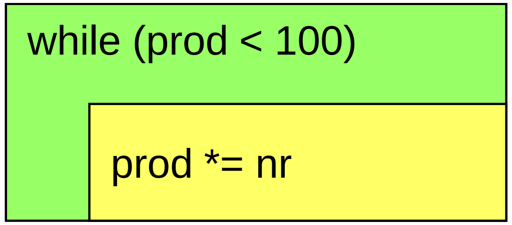


prod < 100

nein

ja

prod *= nr

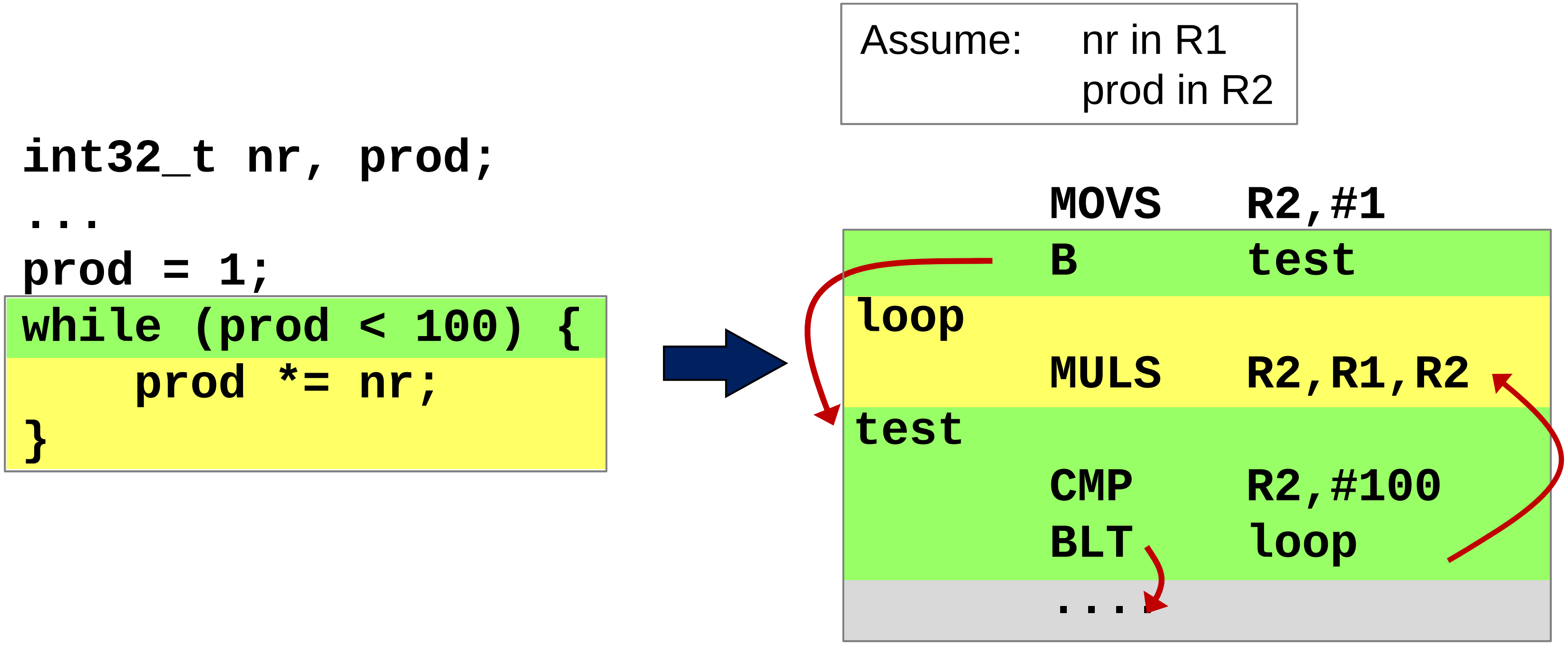


while (prod < 100)

prod *= nr

Loops: While Loops

- Compiler translates loop to assembly code



Assume: nr in R1
prod in R2

```
int32_t nr, prod;
...
prod = 1;
while (prod < 100) {
    prod *= nr;
}
```

```
        MOVS    R2,#1
        B       test
loop
        MULS    R2,R1,R2
test
        CMP     R2,#100
        BLT     loop
        ...
```

Loops: While Loops

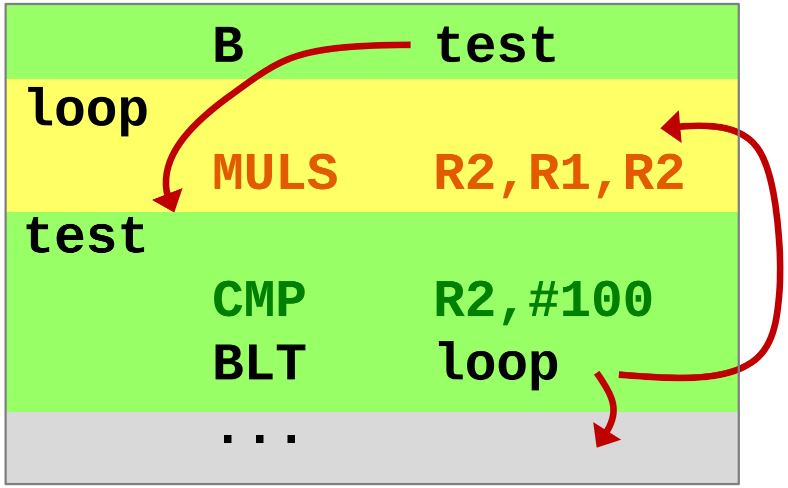
- Compiler takes the following approach
  - Rewrite using goto
  - Re-use structure of do-while

```
while (test-expr)
      body-block
```

```
         goto test
loop:
         body-block
test:
         if (test-expr)
               goto loop;
```

do-while loop

```
while (prod < 100) {
      prod *= nr;
}
```



```
          B          test
loop
          MULS       R2,R1,R2
test
          CMP        R2,#100
          BLT        loop
          ...
```

Loops: For Loops

- For Loops are converted into While Loops
  - break/continue statements require special treatment

```
for (init-expr; test-expr; update-expr)
     body-block
```

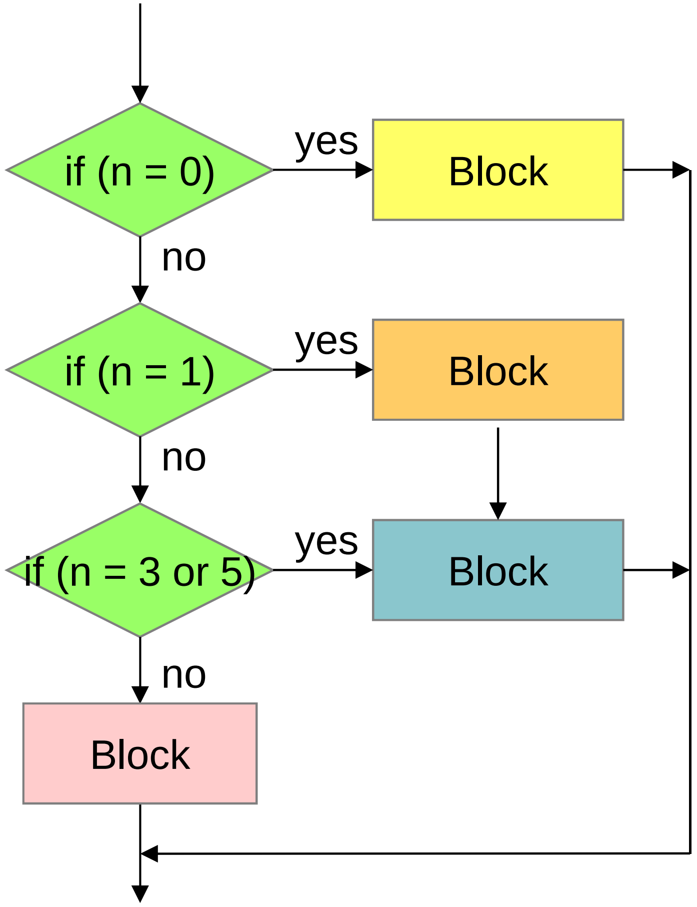
↓

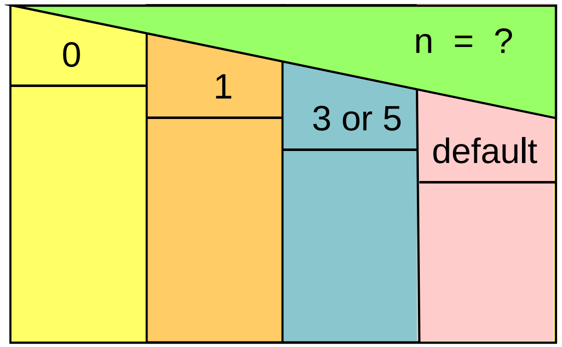
```
init-expr;
while (test-expr) {
     body-block
     update-expr;
}
```

Switch Statements

```
uint32_t result, n;
```

```
switch (n) {
case 0:
    result += 17;
    break;
case 1:
    result += 13;
    //fall through
case 3: case 5:
    result += 37;
    break;
default:
    result = 0;
}
```





Structogram without fall-through

Switch Statements

- **Jump Table**

```
uint32_t result, n;
switch (n) {
case 0:
    result += 17;
    break;
case 1:
    result += 13;
    //fall through
case 3: case 5:
    result += 37;
    break;
default:
    result = 0;
}
```

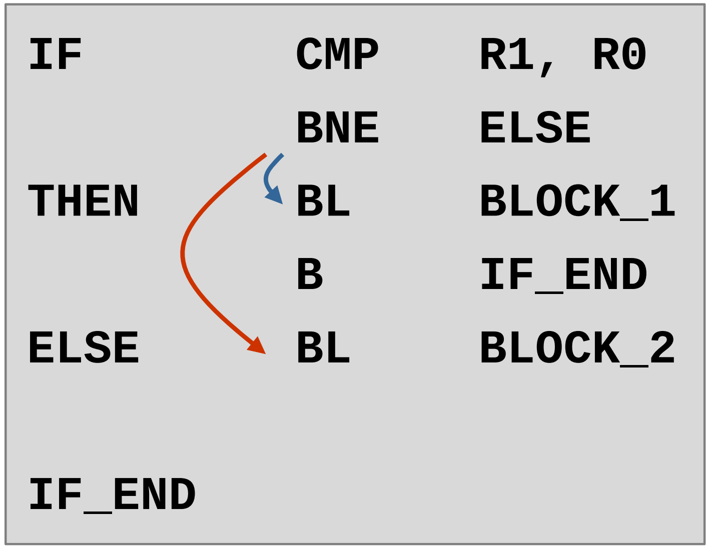
```
NR_CASES        EQU     6

case_switch     CMP     R1, #NR_CASES
                BHS     case_default
                LSLS    R1, #2    ; * 4
                LDR     R7, =jump_table
                LDR     R7, [R7, R1]
                BX      R7
case_0          ADDS    R2, R2, #17
                B       end_sw_case
case_1          ADDS    R2, R2, #13
case_3_5        ADDS    R2, R2, #37
                B       end_sw_case
case_default    MOVS    R2,#0
end_sw_case     ...
```

```
jump_table      DCD     case_0
                DCD     case_1
                DCD     case_default
                DCD     case_3_5
                DCD     case_default
                DCD     case_3_5
```

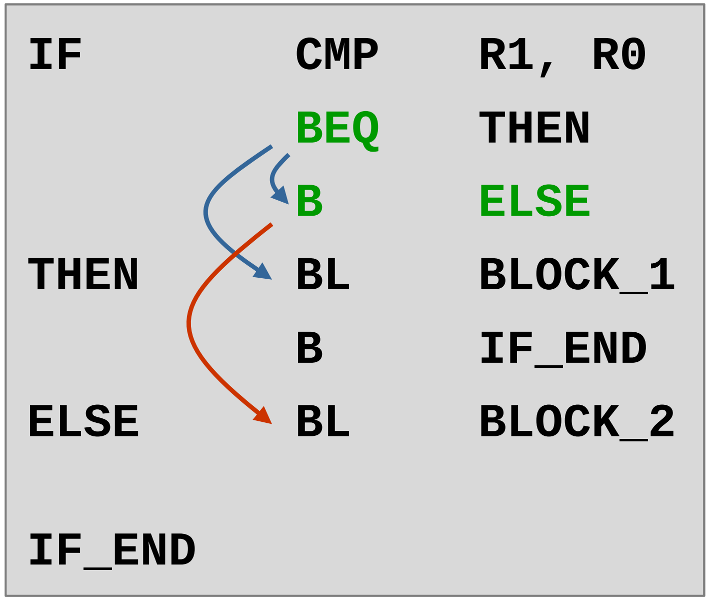
Assume: n in R1
result in R2

Implementation in Assembler

- **Conditional Branches exceeding -256..254 Bytes**



```
IF          CMP     R1, R0
            BNE     ELSE
THEN        BL      BLOCK_1
            B       IF_END
ELSE        BL      BLOCK_2

IF_END
```

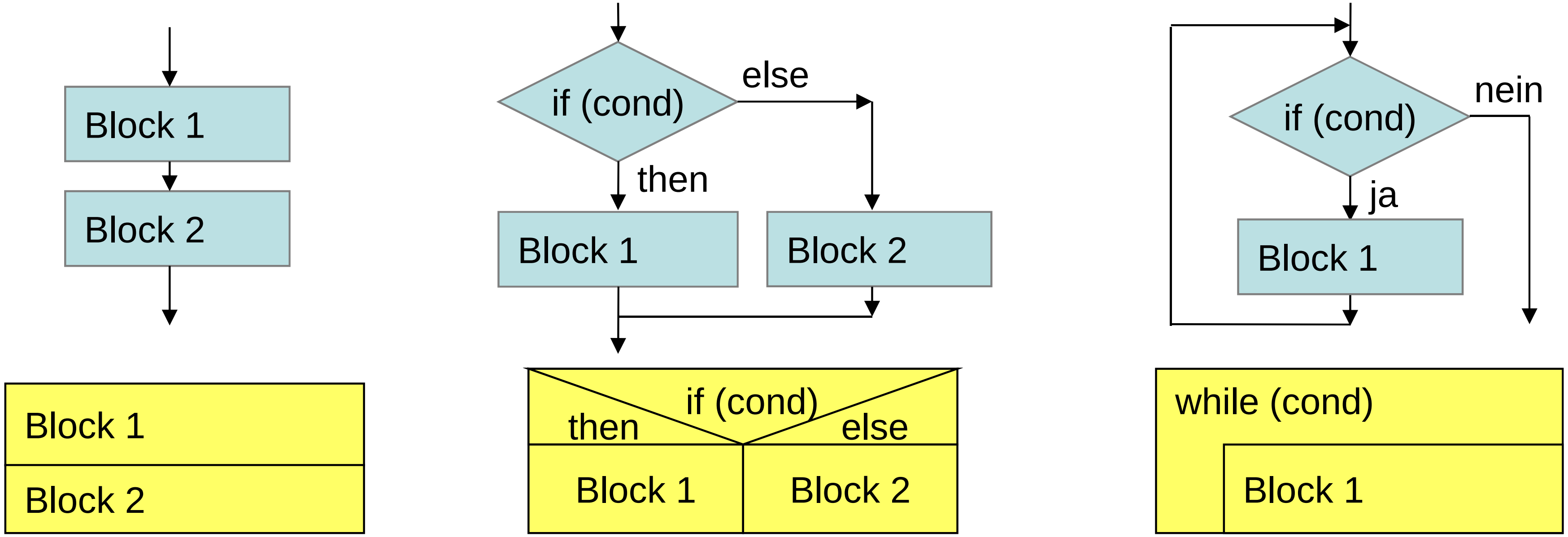


```
IF          CMP     R1, R0
            BEQ     THEN
            B       ELSE
THEN        BL      BLOCK_1
            B       IF_END
ELSE        BL      BLOCK_2

IF_END
```

Conclusion

- Program flow can be represented with three elements

Sequence **Selection** **Iteration/loop**



- High level programming language provides these control structures
- Compiler translates control structures to assembly using conditional and unconditional jumps