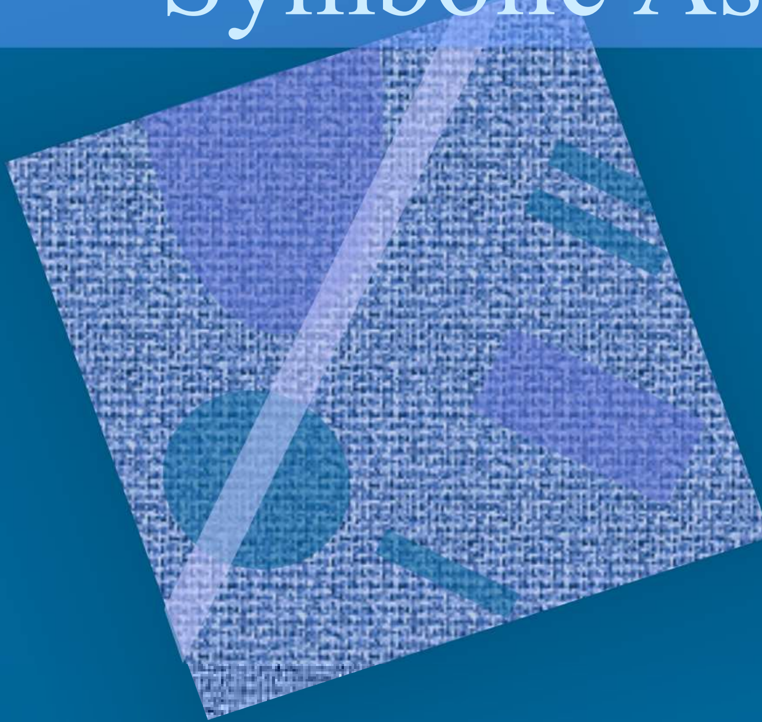
Lecture 4

Subroutine Implementation with Symbolic Assembly Language



Subroutine types,

Parameters

Activation record (AR)

Activation record stack

Recursion

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Subroutine Types

- High level language concepts
  - Subroutine, procedure
    - Parameters (input and output parameters)
  - Function
    - Parameters, return value
  - Method
    - Parameters, possibly return value
- Assembly language concept
  - Subroutine
    - Parameters, possible return value(s)

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Parameters and Return Value

- Formal parameters
  - Defined in subroutine at programming time
  - Certain order and type
  - Return value(s)
    - Handled very much the same way as parameters

```
Print (int x, y)
void Print (int x, y)

Comp(int x): int
int Comp(int x)
```

- Actual parameters and return value
  - Actual parameters are inserted instead of formal parameters at subroutine call time at execution time
  - Return value is obtained at subroutine return time and it is used like any other value

```
Print (5, apu+1);
x = Comp( y+234);
```

Parameter Types

- Call by value parameter
  - Copy of actual parameter value is passed
  - Copied value can be read
  - Copied value can be modified, but original parameter value is safe
- Call by reference parameter
  - Address of actual parameter is passed (it must have address!)
  - Parameter value and address can be read, value can be written
  - Subroutine can modify data in calling routine! Output parameter?
- Call by name parameter *(in interpreted macros or scripts)*
  - Name (string) of actual parameter is passed
  - Name (string) is mapped to value at call time
  - Semantics is determined only at call time

swap(i, j) -- macro, call by name parameters

```
tmp = i;
i = j;
j = tmp;
```

```
swap(x, y);
```

→

```
tmp = x;
x = y;
y = tmp;
```

```
swap(k, T[k]);
```

→

```
tmp = k;
k = T[k];
T[k] = tmp;
```

Discuss

Components of Subroutine Implementation

- Return address
  - Address of the next instruction after the call
- Parameter passing
- Return value passing
- Local variables and other data structures
- Register allocation
  - Calling routine wants to retain values of all registers that it is using
    - Main program, other subroutine, same subroutine, …
  - Subroutine must at the beginning save the values of all (working) registers that it is using, and at the end recover their original values

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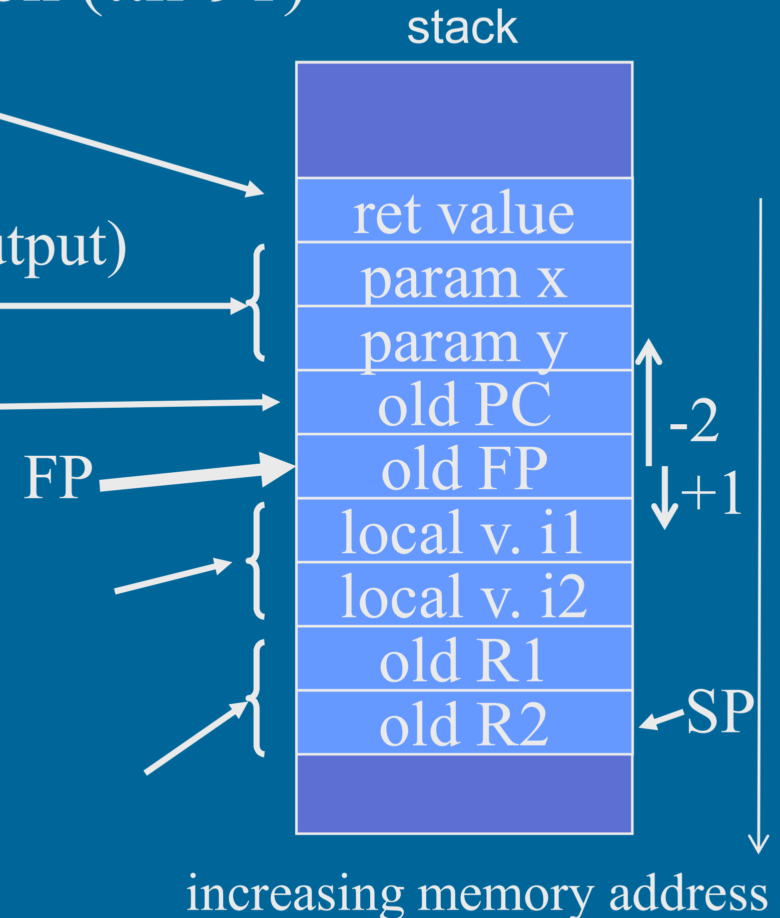
Activation Record (AR) (ttk-91)

(activation frame)

(aktivaatiotietue)

int funcA (int x,y);

- Subroutine implementation (ttk-91)
  - Function return value (return values)
  - Values of all (input and output) parameters
  - Return address
  - Calling routine (old) AR
  - Local variables and other data structures
  - Original values of saved (working) registers



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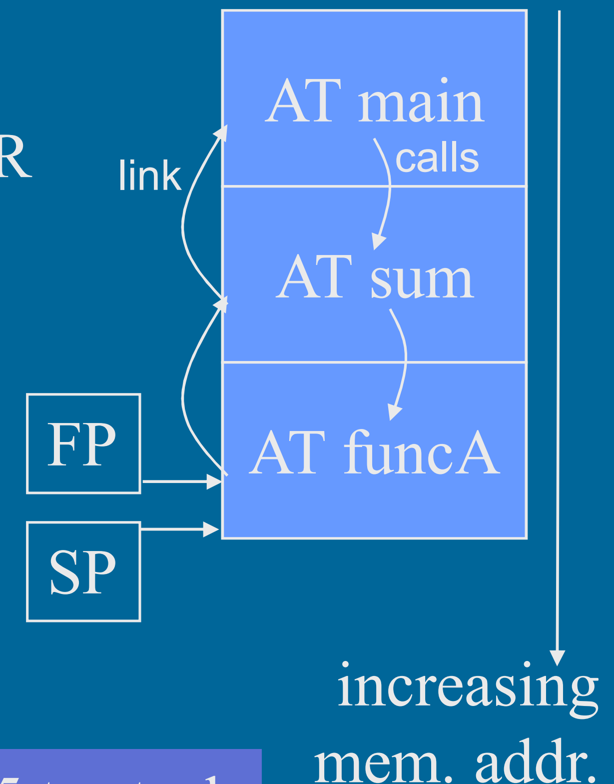
AR Stack in Memory (ttk-91)

aktivaatio-tietuepino

- ARs are reserved and dismantled dynamically (at execution time) from stack (in memory)
  - SP (i.e., R6) points to top of stack
- Activation record stack
  - FP (i.e., R7) points to current AR in <u>specific place</u> (in ttk-91: location of old FP)
- AR (in stack) is built and dismantled with instructions:
  - PUSH, POP, PUSHR, POPR
  - CALL, EXIT (SVC, IRET)

Push value to stack

Push all R0-R5 to stack



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Subroutine Call Implementation

- Implementation split to various units

Calling routine
- Reserve space from stack for return value
- Put parameters (values/addresses) to stack
- Save old PC and FP, set new PC and FP ← CALL instr

Called routine
- Allocate space for local variables (prolog)
- Save old values for used registers to stack (prolog)
- (subroutine implementation – actual work)
- Recover saved register values (epilog)
- Deallocate space for local variables (epilog)
- Recover old PC and FP (epilog) ← EXIT instr
- Deallocate parameter space from stack (epilog) ← EXIT instr

Calling routine
- Take return value from stack

Subroutine Example (13)

```
int fA (int x, y)
{
        int z = 5;

        z = x * z + y;
        return (z);
}

…
T = fA (200, R);
```

subroutine use:

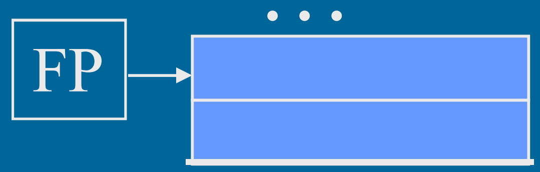
```
R       DC  24
…
PUSH  SP,=0 ; space for ret val
PUSH SP, =200
PUSH  SP, R
CALL  SP, fA
POP      SP, R1
STORE R1, T
…
```

from mem to mem!!

save PC, FP
set PC,
call & return
recover FP, PC
dealloc par space

2nd operand is always reg

current FP



Subroutine example

(no animation)

```
int fA (int x, y)
{
        int z = 5;

        z = x * z + y;
        return (z);
}

…

T = fA (200, R);
```

Subroutine use:

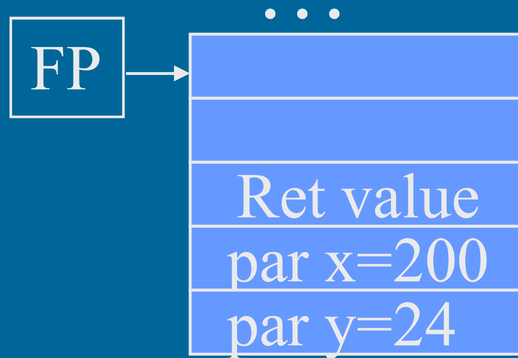
```
R       DC  24
…
PUSH  SP,=0 ; ret. value space
PUSH SP, =200
PUSH  SP, R

CALL  SP, fA

POP     SP, R1
STORE R1, T
…
```

From mem to mem!!

save PC, FP
set PC,
call & return
recov FP, PC

2nd oper is always register

current FP



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Subroutine Example(12)

```
int fA (int x, y)
{
        int z = 5;

        z = x * z + y;
        return (z);
}
…
T = fA (200, R);
```

all references done relative to FP

ret value

Subroutine implementation:

```
retfA   EQU  -4 # return value
parX    EQU  -3 # params
parY    EQU  -2
locZ    EQU  1  # local vars

fA      PUSH  SP, =0 ; alloc Z
        PUSH  SP, R1 ; save R1

        LOAD  R1,=5; init Z
        STORE R1, locZ (FP)

        LOAD R1, parX (FP)
        MUL   R1, locZ (FP)
        ADD   R1, parY (FP)
        STORE R1, locZ (FP)
        STORE R1, retfA (FP)
        POP    SP, R1; recover R1
        SUB    SP, =1 ; free Z
        EXIT   SP, =2 ; 2 param.
```

prolog

epilog

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Discuss

(no animation)

Subroutine Example

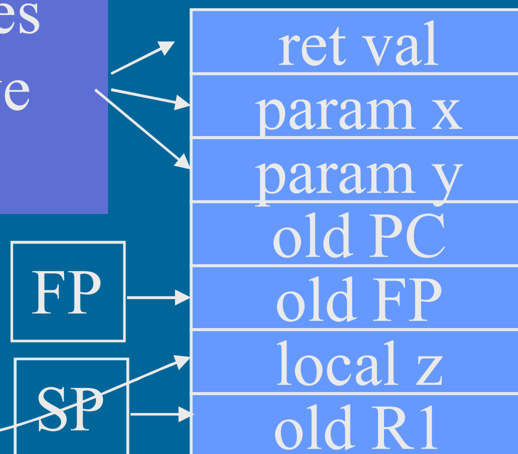
```
int fA (int x, y)
{
        int z = 5;

        z = x * z + y;
        return (z);
}

…

T = fA (200, R);
```

all references done relative to FP



subroutine imlementation:

```
retfA   EQU  -4
parX    EQU  -3
parY    EQU  -2
locZ    EQU   1

fA      PUSH  SP, =0 ; alloc Z
        PUSH  SP, R1  ; save R1

        LOAD  R1,=5; init Z
        STORE R1, locZ (FP)

        LOAD R1, parX (FP)
        MUL   R1, locZ (FP)
        ADD   R1, parY (FP)
        STORE R1, locZ (FP)
        STORE R1, retfA (FP)
        POP    SP, R1; recover R1
        SUB    SP, =1 ; free Z
        EXIT   SP, =2 ; 2 param.
```

prolog

epilog

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Call by Ref Params

Use T = fB(R, S, T)

```
R        DC  24
S        DC 56
T        DC 77
pT       DC  0     ; pointer
…
LOAD   R1, =T    ; initialize pT
STORE  R1, pT
…
PUSH  SP,=0 ; space for ret val
PUSH SP, R  ; call by value
PUSH  SP, =S ; call by reference
PUSH  SP, pT; call by reference
CALL  SP, fB
POP       SP, R1
STORE    R1, T
…
```

Address of variable S
Value of pointer variable pT is address of variable T

Y and Z are call by reference:

```
retfB    EQU  -5  ; return value
parX     EQU  -4  ; call by value
vparY EQU  -3  ; call by reference
vparZ EQU  -2  ; call by reference

fB       PUSH  SP, R1 ; save R1

         LOAD R1, parX (FP)
         MUL   R1, @vparY (FP)
         ADD   R1, @vparZ (FP)
         STORE R1, retfB (FP)
         POP     SP, R1; recover R1
         EXIT   SP, =3 ; 3 param.
```

Procedural OS Service Call

- Same way (e.g.) as subroutine call
  - Instead of CALL instruction use SVC (SuperVisor Call)
- Space for return value?
- Parameters in stack or in registers? (each OS service can be different)
- SVC SP, =5
  - Service routine number as operand
  - Saves PC, FP and SR?
  - Sets PC, FP and SR
- Return with IRET (e.g.)
  - Recover PC, SR and SR
- Remove return value (OK, error) from stack

fOK = ReadBlock (fp, 64)

```
...
PUSH  SP, =0 ;ret val
PUSH  SP, =FileBuffer
PUSH  SP, CharCnt
PUSH  SP, FilePtr

SVC    SP, =ReadBlock

POP      SP, R1
JNZER  R1, FileTrouble
…
```


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Subroutine Call Implementation

- Implementation split to various units

Calling routine
- – Reserve space from stack for return value
- – Put parameters (values/addresses) to stack

CALL instr
- – Save old PC and FP, set new PC and FP

Called routine
- – Allocate space for local variables
- – Save old values for used registers to stack

prolog

- – (subroutine implementation – actual work)
- – Recover saved register values
- – Deallocate space for local variables

EXIT instr
- – Recover old PC and FP
- – Deallocate parameter space from stack

epilog

Calling routine
- – Take return value from stack

Avoid? Make faster?

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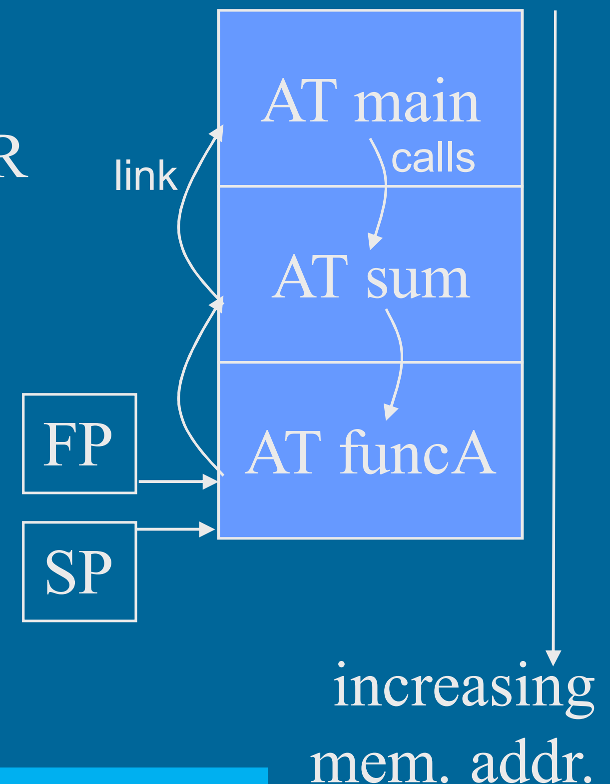

Reference sum in funcA???

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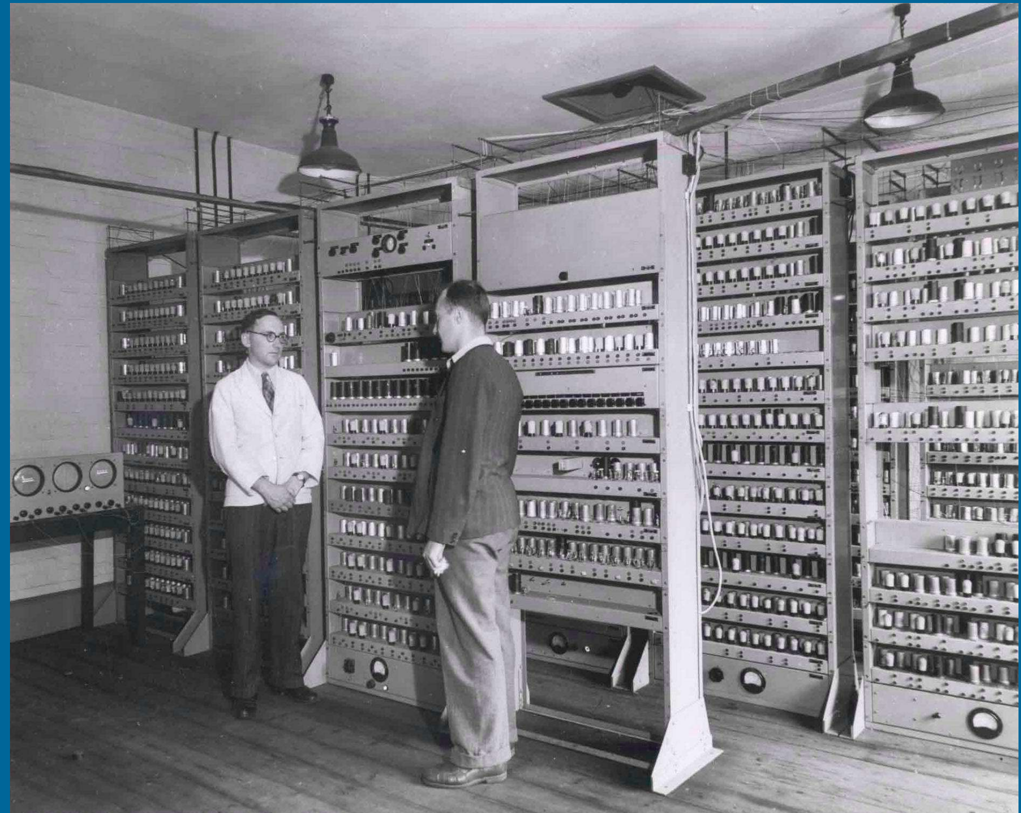
-- END --

M. Wilkes:
EDSAC (1949)

- Register (6) with vacuum tubes
- Instr and data memory,
  32 mercury delay lines, each
  32 words á 18b
- 2's complement int
- Int mult 5.4 ms
- Fractions -1 < x < +1
- No DIV or CALL instr
- Aver speed 650 IPS (instr per sec)
- 1st "stored program" computer (fast instr mem)
- 3000 vacuum tubes, power cons. 12 kW, space 5x4 m
  - Vacuum tubes lasted longer, if they were never turned off



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