CprE 288 – Introduction to Embedded Systems
Exam Review

Course Review for Exam 3

Topics in Assembly Programming

- Data Movement
  - Load immediate
  - Move between registers
  - Move between register and memory
- Logic & Arithmetic
- Control Flow
  - Test/compare register(s)
  - Choose the right branch
- Function call convention
  - Pass parameters and return values
  - Share registers between caller and callee

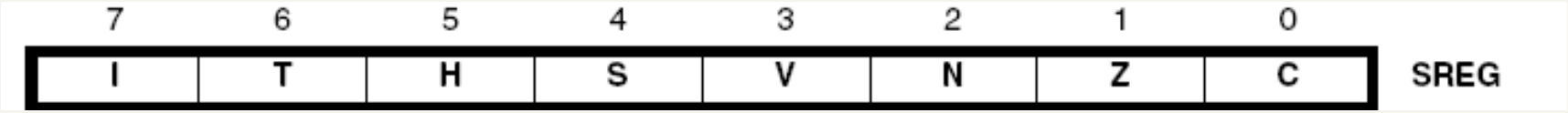
ATMEGA128: GP Registers

- 32 8-bit general purpose registers, R0-R31
  - Used for instructions to execute operations on
  - Used for accessing SRAM
  - Used for passing function parameters and return value
- What is an 8-bit register.
  - Basically just 8 D-Flips connected together

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0

- Some special features to be away of
  - R16 – R31 are the only registers that can have immediate values load to them (e.g. LDI R17, 5)
  - Register pairs R27:R26, R29:R28, R31:R30 can be used as 16-bit pointers (short versions of these registers are X, Y, Z)

Status Register (SREG)



Status Register

Z: Zero flag, whether the result is zero

C: Carry Flag, whether a carry is generated

S: Sign Bit: ***Actual*** result is negative or not

V: Two's Complement Overflow Flag

N: Negative Flag, whether the result is negative or not with signed operands

H: Half Carry Flag

I: Global Interrupt Enable

T: Bit Copy Storage

Instructions to move data: Summary

- LDI Rd, K Load Immediate *Rd ← K* 1 clk
- MOV Rd, Rr Move Between Registers *Rd ← Rr* 1 clk
- MOVW Rd, Rr Move word: *Rd+1:Rd ← Rr+1:Rr* 1 clk

- LDS Rd, (k) Load Direct *Rd ← (k)* 2 clks
  - *Note: There is a ST version for each LD (except for LDI)*
- LD Rd, Y Load Indirect *Rd ← (X)* 2 clks
- LD Rd, Y+ Load Indirect & Post-Inc. *Rd←(X), X← X + 1* 2clks
- LD Rd, -Y Load Indirect & Pre-Decr. *X← X - 1, Rd←(X),* 2clks
- LDD Rd, Y+q Load Indirect + offset. *Rd ←(X+q)* 2 clks

Instructions to move data: Summary

- STS K, Rd Store Direct *Rd* ← *(k)* 2 clks
- ST Y, Rd Load Indirect *Rd* ← *(X)* 2 clks
- ST Y+, Rd Load Indirect & Post-Inc. *Rd*←*(X), X*← *X + 1* 2clks
- ST -Y, Rd Load Indirect & Pre-Decr. *X*← *X - 1, Rd*←*(X)* 2clks
- STD Y+q, Rd Load Indirect + offset. *Rd* ←*(X+q)* 2 clks

Three **indirect address (pointer) registers**: X, Y, and Z

X ⇔ R27:R26

Y ⇔ R29:R28

Z ⇔ R31:R30

LDD/STD works for Y and Z only, not X

Arithmetic Instruction

Overview of arithmetic instructions

Addition: ADD, ADC, ADIW

Subtraction: SUB, SUBI, SBC, SBCI, SBIW

Logic: AND, ANDI, OR, ORI, EOR

Compliments: COM, NEG

Register Bit Manipulation: SBR, CBR

Register Manipulation: INC, DEC, TST, CLR, SER

Multiplication1: MUL, MULS, MULSU

Fractional Multiplication1: FMUL, FMULS, FMULSU

Source: AVR Studio 4 and ATmega128: A Beginner's Guide, Page 31

HW10 Questions

```
char ch1 = 0x30;
char ch2 = 0x40;
int a = 0x1010;

ch1 = ch2;

a = ch1;
```

HW11 Questions

```
signed char ch1;
signed char ch2;
signed char flag;
int a;
int b;
signed char *pch;
int *pint;
```

```
*pch = ch1;

a = *pint;

pint = &b;

a = ch1 * ch2;

ch1 = ch1 & ch2;
```

Conditional Branches

Commonly used branches

BREQ: **EQ**ual, signed or unsigned doesn't matter

BRNE: **N**ot **E**qual, signed or unsigned doesn't matter

BRLT: **L**ess **T**han, for signed type

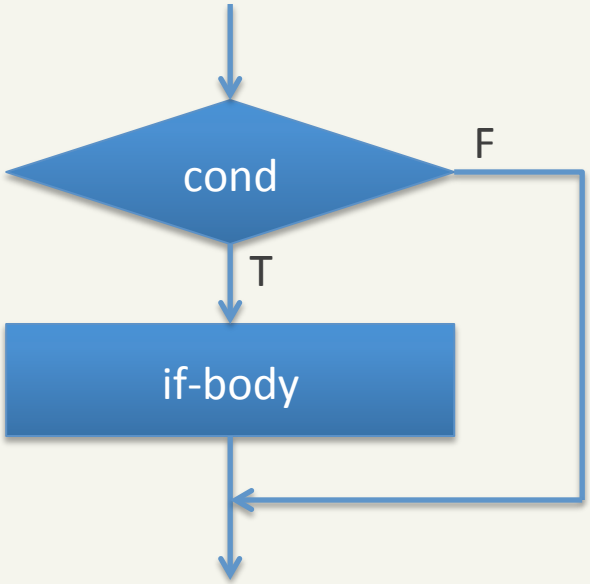
BRGE: **G**reater than or **E**qual, for signed type

BRLO: **LO**wer than, for unsigned type

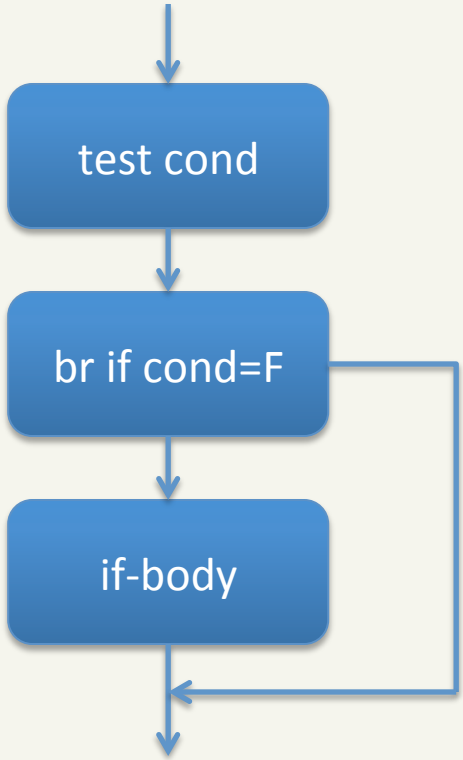
BRSH: **S**ame or **H**igher than, for unsigned type

If-Statement: Structure

Control and Data Flow Graph

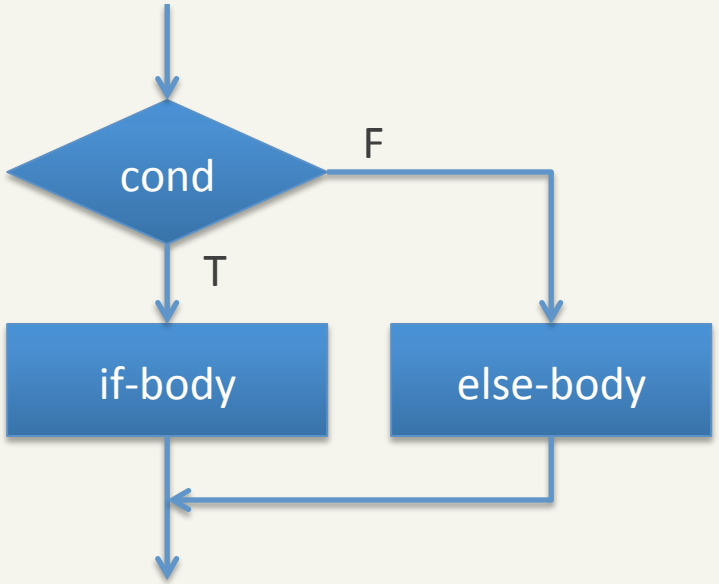


Linear Code Layout

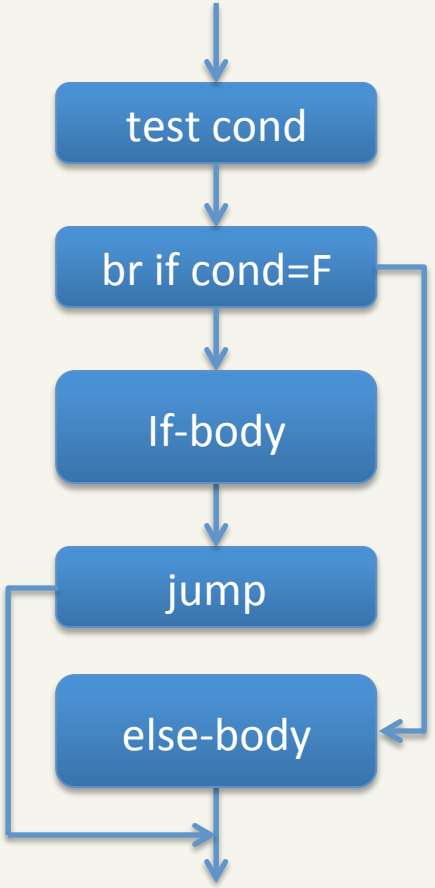


If-Else Statement: Structure

Control and Data Flow Graph



Linear Code Layout



HW12 Questions

```
extern int a, b, max;

if (a > b)
   max = a;
else
   max = b;
```

What if

```
   extern unsigned a, b, max
```

HW12 Questions

```
extern int a;
signed char flag;

if (a <= 20)
   flag = 0;
else
   flag = 1;
```

Caveats with Condition

Two types of if-conditions are trouble-free

if (a >= b)	branch if a<b, use BRLT
if (a < b)	branch if a≥b, use BRGE

What about

if (a > b)	⇔	if (b < a)
if (a <= b)	⇔	if (b >= a)
if (a > 10)	⇔	if (a >= 11)
if (a <= 10)	⇔	if (a < 11)

HW12 Questions

```
extern int a, b;
signed char flag;

if (flag)
  a = b;
else
  b = a;
```

AVR-GCC Call Convention: Parameters and Return Value

Function parameters

- R25:R24, R23:R22, ..., R9:R8
- All aligned to start in even-numbered register
  i.e. char will take two registers (use the even one)
- A long type uses two pairs
- Extra parameters go to stack

Function return values

- 8-bit in r24 (with r25 cleared to zero), or
- 16-bit in R25:R24, or
- 32-bit in R25-R22, or
- 64-bit in R25-R18

AVR-GCC Call Convention: Register Usage

How to share registers between caller and callee?

Callee-save/Non-volatile: R2-R17, R28-R29

Caller may use them for free, callee must keep their old values

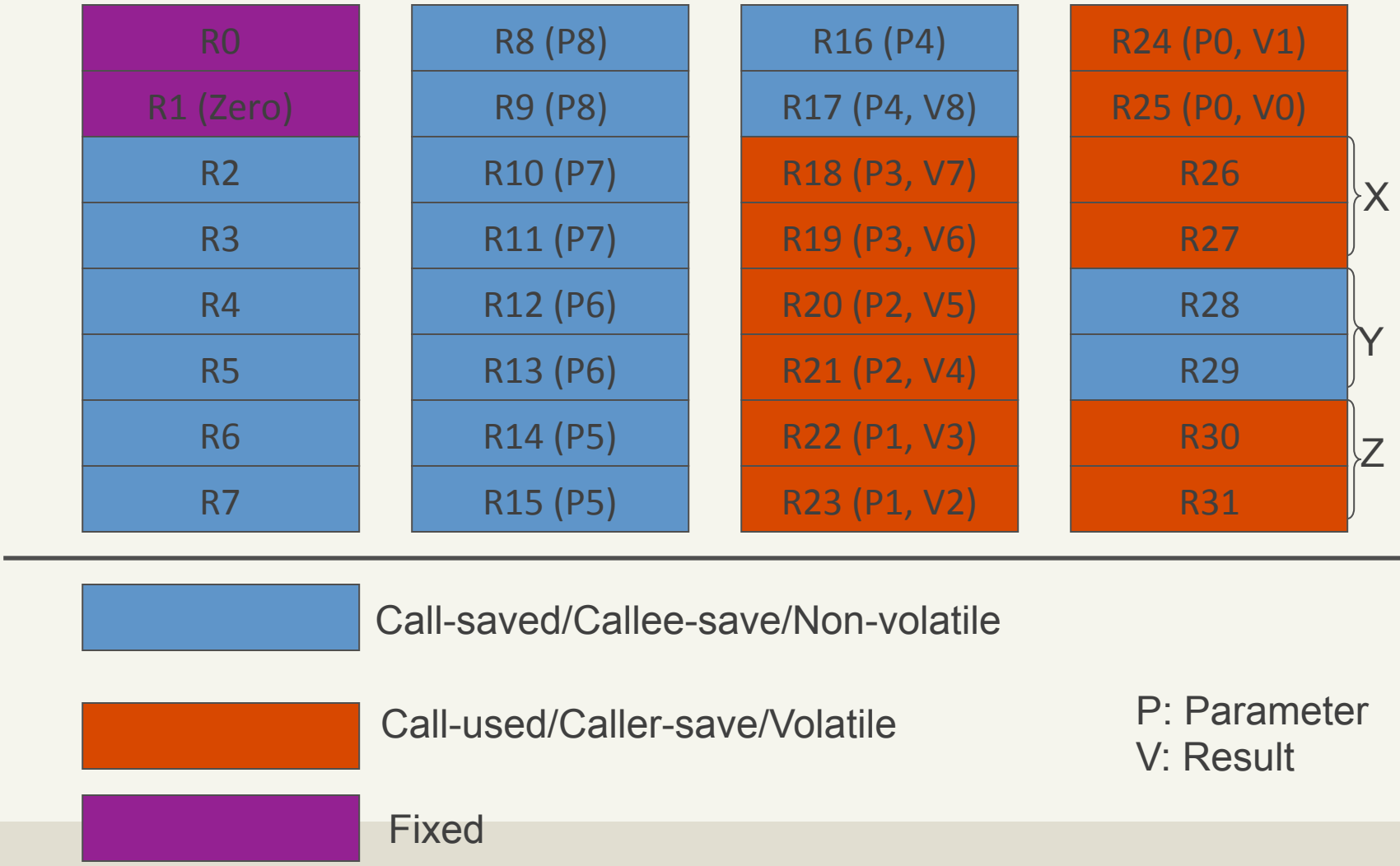
Caller-save/Volatile: R18-R27, R30-R31

Callee may use them for free, caller must save their old values if needed

Fixed registers

- R0: Temporary register used by gcc (no need to save)
- R1: Should be zero

AVR-GCC Call Convention



HW12 Questions

```
// Return the max of two integers
unsigned max(unsigned a, unsigned b);
```

HW12 Questions

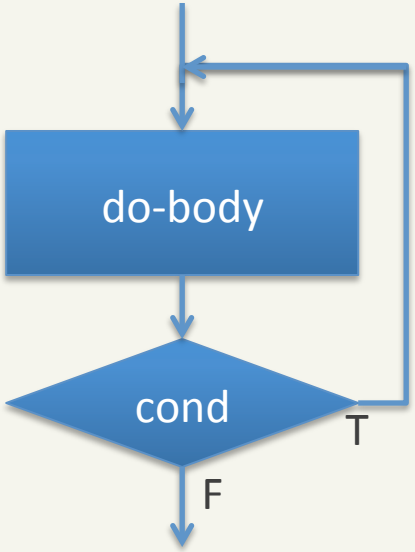
```
// Copy the contents of array X into array Y.
// Both arrays have N elements.
void copyArray(int X[], int Y[], int N);
```

HW12 Questions

```
// Find out the maximum value of an
// array, return the value. The array
// has N elements
int maxOfArray(int X[], int N);
```

DO-WHILE Loop

Control and Data Flow Graph



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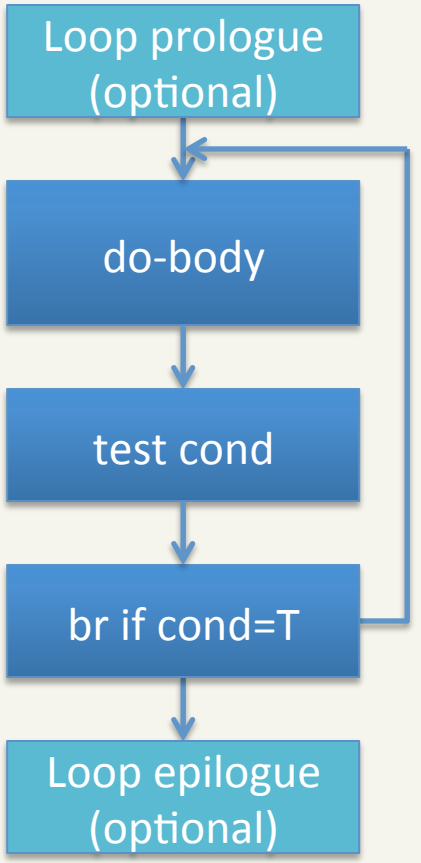
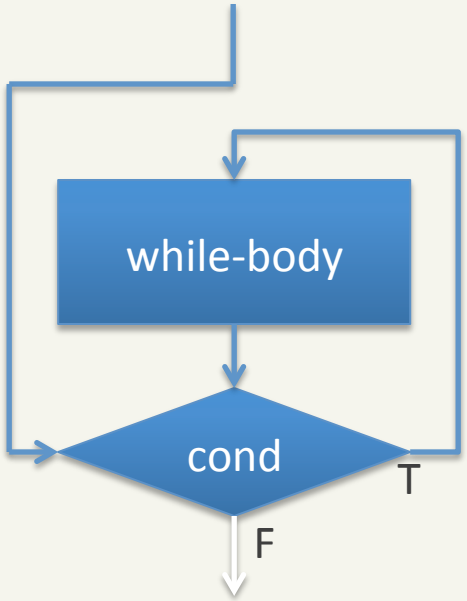


WHILE Loop

Control and Data Flow Graph



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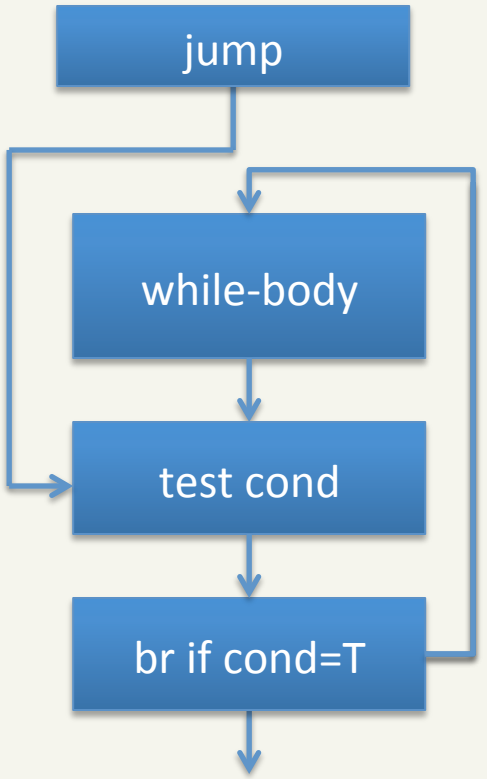
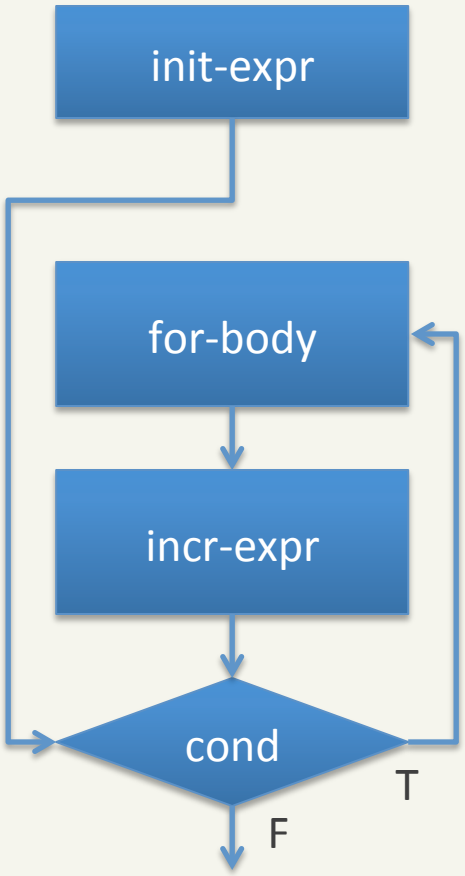


(optional prologue and epilogue not shown)

FOR Loop

Control and Data Flow Graph



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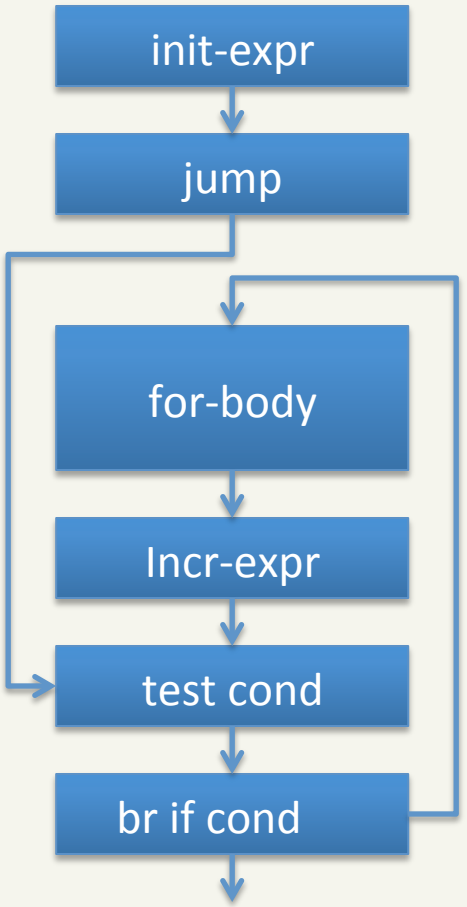

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