# MeggyJava to AVR Assembly

**Today**

- MeggyJava class example
- MeggyJrSimple C++ library
- ATmega328p chip
- AVR assembly especially for PA3ifdots.java

**Next week**

- Post possible peer evaluation criteria for PA1 on the google form posted on piazza. (Potential extra credit).
- PA1: Start PA3whiledots.java.s. It is due in 13 days along with demo!
- HW2: Due Tuesday September 6th
  - Reading assignment before Thursday is posted on class schedule
  - Thursday will be Haskell intro
  - Friday will be Haskell in discussion section

# Class Example

**Let's write a MeggyJava program**

- Infinite loop
- If we press the A button then let's light a pixel.
- If we press the B button then …
- How can we have variables?
- …

# Meggy Jr Simple Library

**Key concepts**

- LED screen (pixels)
- Auxiliary LEDs
- Buttons
- Speaker

- Check the AVR-G++ generated code for library calls, and their calling sequence. AVR-G++ (and also MeggyJava) links in run time libraries:
- **Meggy Jr** Library provided an interface to set and read values in the Display Memory
- **Meggy Jr Simple** lies on top of Meggy Jr library, and provides a higher level API with names for e.g. colors
- Michelle Strout and students (honors projects / theses) added some functionality to the Meggy Jr Simple library

# Meggy Jr Simple Library functions

ClearSlate() -- erase the whole slate

DrawPx(x,y,color) -- set pixel (x,y) to color

DisplaySlate() -- copy slate to LED Display Memory

SetAuxLEDS(value)

- -- 8 LEDS above screen numbered 1, 2,4,..,128 (left to right)
  - value is a byte encoding in binary which LEDs are set
  - SETAuxLEDS(53) sets LEDS 1,4,16, and 32

ReadPx(x,y) -- returns byte value of pixel (x,y)

- CheckButtonsDown()
- -- sets 6 variables: Button_(A|B|Up|Down|Left|Right)

GetButtons() returns a byte (B,A,Up,Down,Left.Right: 1,2,4,8,16,32)

ToneStart(divisor, duration)

- -- starts a tone of frequency 8 Mhz/divisor for ~duration milliseconds
  - There are predefined tones.

Check out MeggyJrSimple.h

# Example AVR-G++ program

```
 /*  1/24/11, MS, goal is to exercise all of the routines in MeggyJrSimple
*/
 #include "MeggyJrSimple.h"
 #include <util/delay.h>
 int main (void) {
     MeggyJrSimpleSetup();
     DrawPx(0, 1, Red);    // should display red LED
     DisplaySlate();
     // If <0,1> pixel is red, set auxiliary light
     if (ReadPx(0,1)==Red) {  SetAuxLEDs (4); }
     while (1){
          CheckButtonsDown();
           if (Button_A) {   Tone_Start(ToneC3, 1000); }
           if (Button_B) {   SetAuxLEDs(16); }
           if (4 & GetButtons()) {  SetAuxLEDs(31);   } //
           if (Button_Up) { delay_ms(256); }
     }
     return 0;
  }
```

# AVR Instruction Set Architecture, or Assembly

**ATmega328p**

**AVR ISA**

**Handling GetButton and SetPixel calls, (Calling Convention)**

**Handling if statements (Condition Codes and Branches)**

**Handling expression evaluation (Operations and Stack instructions)**

**Variables on the stack and in the heap**

# ATmega328p

**Terminology**

– Atmel, a company

– AVR, 8-bit RISC instruction set architecture for a microcontroller

– ATmega328p, AT for Atmel, MegaAVR microcontroller, 32kb flash, 8-bit AVR, p=low power

– Arduino, programming environment for various boards with some AVR chips

**Uses**

– Very popular for hobbyists

http://hacknmod.com/hack/top-40-arduino-projects-of-the-web/

http://www.engineersgarage.com/articles/avr-microcontroller

– Industry: Whirlpool appliances, electric car charger, medical products, …

# AVR Instruction Set Architecture (ISA)

**AVR is an 8-bit (1 byte) Harvard RISC Architecture**

- Two 8-bit words (and register pairs e.g. R0, R1) can be interpreted as 16-bit ints

**Harvard: There are separate spaces in memory**

- data space (data) (0-RAMEND)
- program space (text) (0-FLASHEND)

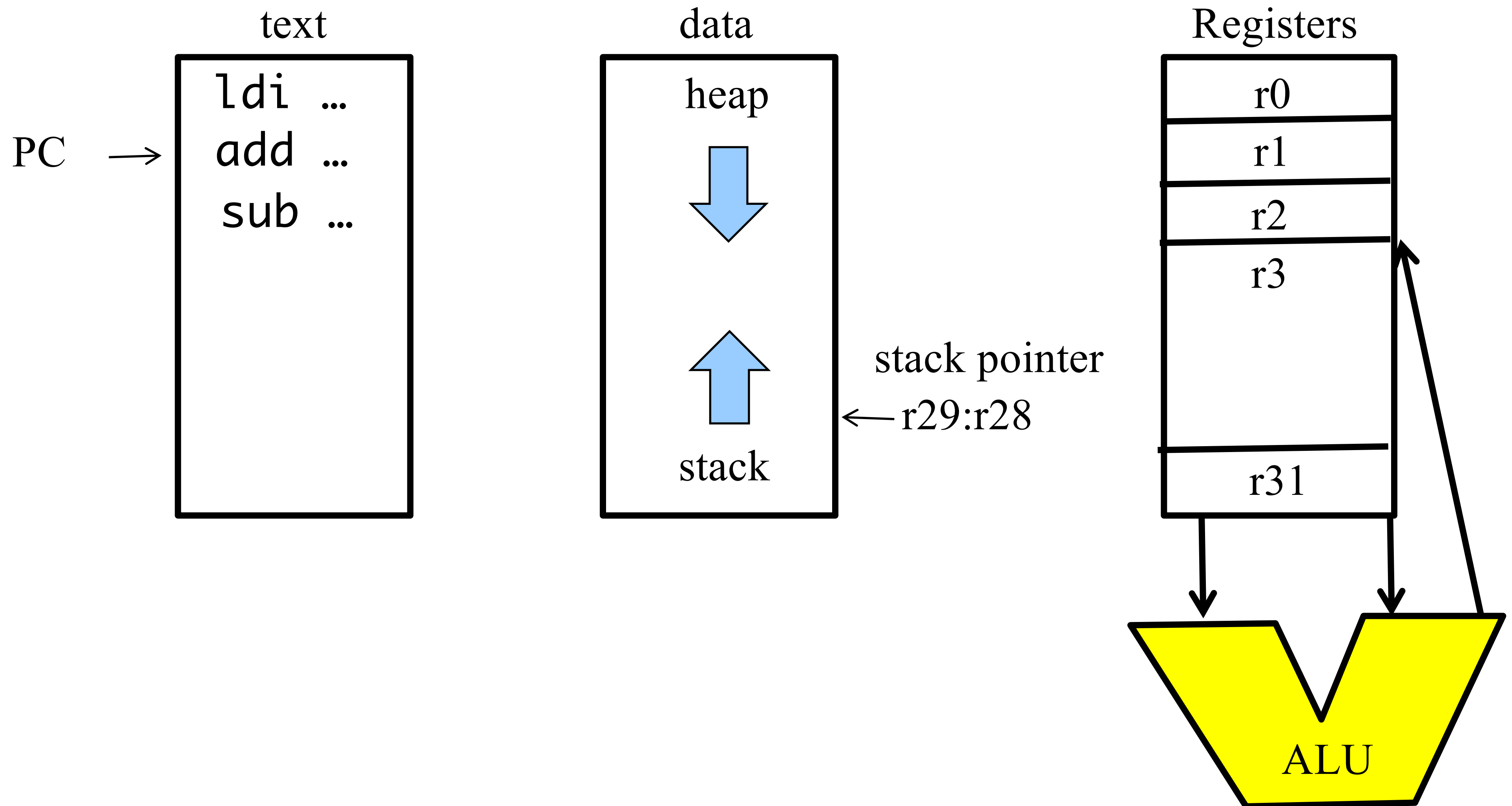
**There are 32 Registers, organized in a register file R0 – R31**

**There is a run time Stack (stack pointer/ push / pop) in dataspace**

**RISC: Reduced Instruction Set, What does it mean?**

- Only load/store instructions can access the memory
- Most instructions work on registers only and have therefore fully predictable timing (#clocks to execute)
- No self-modifying code.

# Execution Model



# Meggy Java program for translation to AVR (calls)

```
/**
 * PA3ifdots.java
 *
 * An example similar to the one for PA1.
 * The language features will be from the PA3 grammar.
*/

import meggy.Meggy;

class PA3ifdots {

    public static void main(String[] whatever){
        if (Meggy.checkButton(Meggy.Button.Up)) {
            Meggy.setPixel( (byte)3, (byte)(4+3), Meggy.Color.BLUE );
        }
        if (Meggy.checkButton(Meggy.Button.Down)) {
            Meggy.setPixel( (byte)3, (byte)0, Meggy.Color.RED );
        }
    }
}
```

# Calling convention

**Calling convention is interface between caller and callee**

- callers have to pass parameters to callee
- callees have to pass return values to caller
- callers and callees save registers

  caller saves registers r18-r27, r30-r31

  callee saves registers r2-r17, r28-r29
- Arguments - allocated left to right, r25 to r8

| | |
|---|---|
| r24, r25 | parameter 1, only use r24 if just a byte parameter |
| r22, r23 | parameter 2 |
| … r8, r9 | parameter 9 |

**Return values**

8-bit in r24, 16-bit in r25:r24,

up to 32 bits in r22-r25, up to 64 bits in r18-r25.

# Meggy Java program for translation to AVR (calls)

```
/* PA2bluedot.java */
import meggy.Meggy;

class PA2bluedot {
       public static void main(String[] whatever){
               Meggy.setPixel( (byte)1, (byte)2, Meggy.Color.BLUE );
        }
}
```

```
        .file    "main.java"
__SREG__ = 0x3f
__SP_H__ = 0x3e
__SP_L__ = 0x3d
__CCP__  = 0x34
__tmp_reg__ = 0
__zero_reg__ = 1
        .global __do_copy_data
        .global __do_clear_bss
        .text
.global main
        .type    main, @function
main:
/* prologue: function */
/* frame size = 0 */
        call _Z18MeggyJrSimpleSetupv
        ldi r24,lo8(1)
        ldi r22,lo8(2)
        ldi r20,lo8(5)
        call _Z6DrawPxhhh
        call _Z12DisplaySlatev
endLabel:
        jmp endLabel
        ret
        .size    main, .-main
```

# Meggy Java program for translation to AVR (if statement)

```
/**
 * PA3ifdots.java
 *
 * An example for the students to code up in AVR assembly for PA1.
 * The language features will be from the PA3 grammar.
*/

import meggy.Meggy;

class PA3ifdots {

    public static void main(String[] whatever){
        if (Meggy.checkButton(Meggy.Button.Up)) {
            Meggy.setPixel( (byte)3, (byte)(4+3), Meggy.Color.BLUE );
        }
        if (Meggy.checkButton(Meggy.Button.Down)) {
            Meggy.setPixel( (byte)3, (byte)0, Meggy.Color.RED );
        }
    }
}
```

# AVR Status Register

**Status Register (SREG)** keeps some bits (flags) that represent an effect of a previously executed instruction

**Some important flags (there are more, check the Atmel AVR manual)**

C: Carry flag, a carry occurred (bit overflow)

Z: Zero flag, result was 0

N: Negative flag, result was negative

- The effect on flags by instruction execution can be cleared (0), set (1), unaffected (-)

**Conditional Branch instructions (breq, brlo, brlt, brne) use these flags**

brne label

# Flags and Conditional Branches

**The comparison and arithmetic instructions set the flags (Z,N,C,…)**

**Comparison instructions:** cp cpc tst

**Arithmetic instructions:**

adc add sbc sub neg and or eor lsl lsr muls rol ror

**Conditional branch instructions inspect the flags:**

**Branch instructions:** brlo brlt brmi brne

**Branches branch PC relative and have a limited range (-64 .. 63)**
**Therefore, if we don't know how far a branch will branch, we need to branch to a jump instruction (jmp), which can reach all instructions**

# Meggy Java program for translation to AVR (if statement)

```
/* PA5movedot.java */
…
 if (Meggy.checkButton(Meggy.Button.Up)) {
   this.movedot(curr_x, (byte)(curr_y+(byte)1));
   Meggy.toneStart(localvar, 50);
 } else {}
```

```
…
 #### if statement

    ### MeggyCheckButton
    call     _Z16CheckButtonsDownv
    lds     r24, Button_Up
    # if is zero, push 0 else push 1
    tst     r24
    breq    MJ_L6
MJ_L7:
    ldi     r24, 1
    jmp     MJ_L8
MJ_L6:
MJ_L8:
```

```
    # push one byte expression onto stack
    push   r24
    # load condition and branch if false
    # load a one byte expression
    pop    r24
    #load zero into reg
    ldi    r25, 0
    #use cp to set SREG
    cp     r24, r25
    brne   MJ_L4
    jmp    MJ_L3

    # then label for if
MJ_L4:
    # then body …
    jmp    MJ_L5

    # else label for if
MJ_L3:
    # done label for if
MJ_L5:
```

# Meggy Java program for translation to AVR (expression eval)

```
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*/

import meggy.Meggy;

class PA3ifdots {

    public static void main(String[] whatever){
        if (Meggy.checkButton(Meggy.Button.Up)) {
            Meggy.setPixel( (byte)3, (byte)(4+3), Meggy.Color.BLUE );
        }
        if (Meggy.checkButton(Meggy.Button.Down)) {
            Meggy.setPixel( (byte)3, (byte)0, Meggy.Color.RED );
        }
    }
}
```

# Arithmetic: bytes and ints

**AVR is an 8 bit architecture, but has support for 16 bit ints.**

**This is accomplished by having register pairs, and having certain instructions taking certain flags into account:**

```
# add r1:r0 to r3:r2
add r2,r0  # Rd = Rd + Rr  sets C
adc  r3,r1  # Rd = Rd + Rr + C
```

**Subtraction:** check out "sub" and "sbc"
**Multiplication:** check out "muls"
**Bitwise AND:** check out "and"

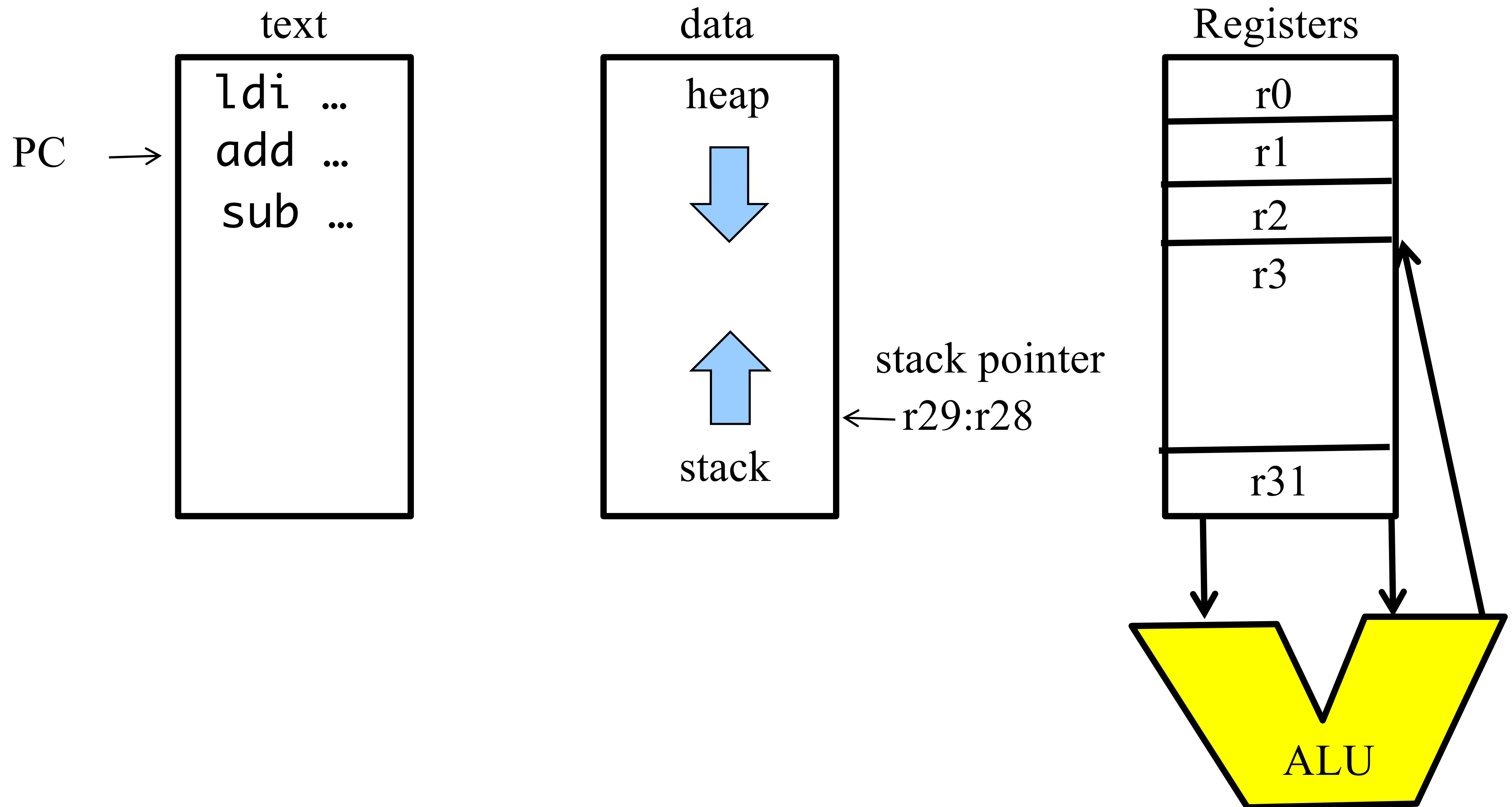
# Meggy Java program for translation to AVR (expression eval)

```
/* PA5movedot.java */
…
return ((byte)(0-1) < x) …
```

```
    .file          "PA5movedot.java"
# Load constant int 0
ldi    r24,lo8(0)
ldi    r25,hi8(0)
# push two byte expression onto stack
push   r25
push   r24

# Load constant int 1
ldi    r24,lo8(1)
ldi    r25,hi8(1)
# push two byte expression onto stack
push   r25
push   r24
# load a two byte expression off stack
pop    r18
pop    r19
```

```
# load a two byte expression off stack
pop    r24
pop    r25

# Do INT sub operation
sub    r24, r18
sbc    r25, r19
# push hi order byte first
# push two byte expression onto stack
push   r25
push   r24

# Casting int to byte by popping
# 2 bytes off stack and only push low bits
# back on.  Low bits are on top of stack.
pop    r24
pop    r25
push   r24
```

# Variables on the Stack and Heap



# Stack and heap

**Stack pointer:**

points at first available location on the run time stack

varies during expression evaluation

**Frame pointer:**

a fixed pointer in the stack frame so that parameters and local variables can be associated with an offset from the frame pointer

**Allocating space on the heap with malloc library function:**

malloc allocates n consecutive bytes in the heap and returns the address of the first byte allocated.

(Will see examples of this later).

## Data Indirect addressing

**Some register pairs are used for indirect addressing.**

There are special names for these Indirect Address Registers

**X=R27:R26, Y=R29:R28, Z=R31:R30**

```
in r28,__SP_L__     // putting the stack pointer into r29:r28
in r29,__SP_H__


ldd     r24, Y+3    // load byte that is 3 bytes from address in r29:r28
                    // r24 = M[r29:r28 + 3]

std     Y+1, r24    // store value in r24 to address r29:r28+1
                    // M[r29:r28 + 1] = r24
```

**There are pre-decrement and post-increment indirect addressing modes for data structure (Stack) manipulation**

**The run time stack is implicitly manipulated with (push) and (pop) instructions, SP is the name of the stack pointer**

# Before Next Time

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