CS3350B Computer Organization
Chapter 1: CPU and Memory
Some Locality Examples

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Instruction Locality Example 1

A C function and program.

```
int doSomething() {
    int z = 10+12;
    return z;
}

int main() {
    int a = 1;
    int b = 2;
    doSomething();
    return 0;
}
```

That program in assembly (MIPS).

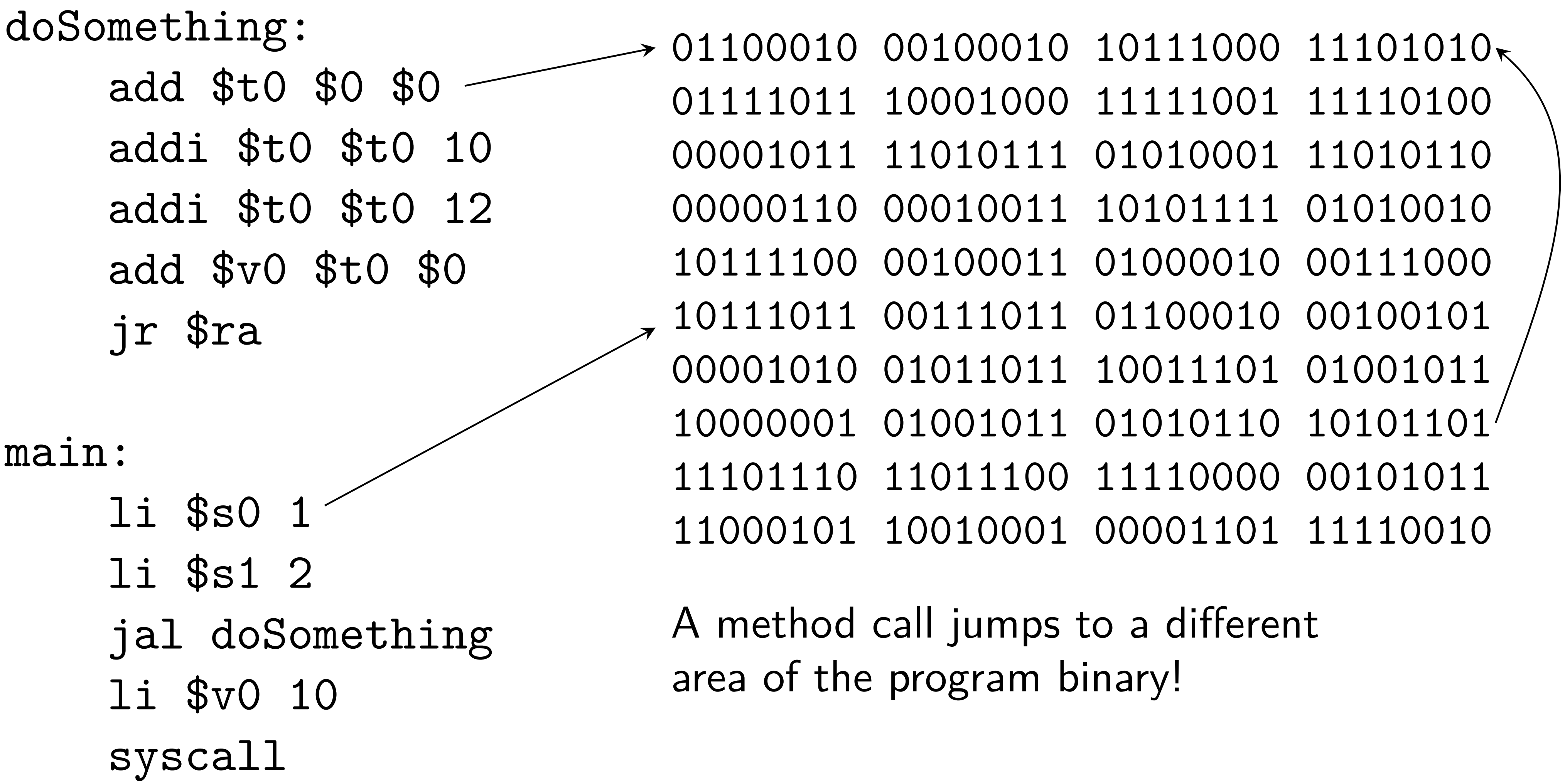
```
doSomething:
    add $t0 $0 $0
    addi $t0 $t0 10
    addi $t0 $t0 12
    add $v0 $t0 $0
    jr $ra

main:
    li $s0 1
    li $s1 2
    jal doSomething
    li $v0 10
    syscall
```

Instruction Locality Example 1

That program in assembly (MIPS).

Program Binary (fake).



```
doSomething:
    add $t0 $0 $0
    addi $t0 $t0 10
    addi $t0 $t0 12
    add $v0 $t0 $0
    jr $ra

main:
    li $s0 1
    li $s1 2
    jal doSomething
    li $v0 10
    syscall
```

```
01100010 00100010 10111000 11101010
01111011 10001000 11111001 11110100
00001011 11010111 01010001 11010110
00000110 00010011 10101111 01010010
10111100 00100011 01000010 00111000
10111011 00111011 01100010 00100101
00001010 01011011 10011101 01001011
10000001 01001011 01010110 10101101
11101110 11011100 11110000 00101011
11000101 10010001 00001101 11110010
```

A method call jumps to a different area of the program binary!

Instruction Locality Example 2

An inlined C function and program.

```
inline int doSomething() {
    int z = 10+12;
    return z;
}

int main() {
    int a = 1;
    int b = 2;
    doSomething();
    return 0;
}
```

That program in assembly (MIPS).

```
main:
    li $s0 1
    li $s1 2
    add $t0 $0 $0
    addi $t0 $t0 10
    addi $t0 $t0 12
    add $v0 $t0 $0
    li $v0 10
    syscall
```

Instruction Locality Example 2

```
main:
    li $s0 1
    li $s1 2
    add $t0 $0 $0
    addi $t0 $t0 10
    addi $t0 $t0 12
    add $v0 $t0 $0
    li $v0 10
    syscall
```

```
10011010 01110111 00101101 00110000
00010110 11011011 11000000 01101011
01001000 10011111 11010100 10100101
10000011 01101111 10110100 01100001
00000101 01110010 00101010 00110101
00110000 00111010 11101001 11110010
10010000 00110001 11110000 00100000
10101111 00110101 00100100 01110000
```

Inlined function $\implies$ All instructions are sequential.

Data Locality Example Without Arrays (1/2)

Highly simplified example.

Assume CPU has no registers and cache is 4 words using LRU.

```
int fibonacci1(int n) {
    int t1 = 0, t2 = 1;
    if (n < 1) {
        return t1;
    }
    if (n < 2) {
        return t2;
    }

    for (int i = 1; i < n ++i) {
        int t3 = t1 + t2;
        t1 = t2;
        t2 = t3;
    }
    return t3;
}
```

Cache Contents				Inst.	M/H
n				`start`	M
t1	n			`t1 = 0`	M
t2	t1	n		`t2 = 1`	M
n	t2	t1		`n < 1; n < 2`	H
i	n	t2	t1	`i = 0; i < n`	M; H
t1	t2	i	n	`t1 + t2`	H
t3	t1	t2	n	`t3 = t1 + t2`	M
t1	t2	t3	n	`t1 = t2`	H
t2	t3	t1	n	`t2 = t3`	H
i	t2	t3	t1	`++i`	M
i	n	t2	t3	`i < n`	M
t1	t2	i	n	`t1 + t2`	M
t3	t1	t2	n	`t3 = t1 + t2`	M
⋮					

(1) “Longer” loop causes conditional to always miss

(2) Initializing variables far away from use ruins cache of function caller.

Data Locality Example Without Arrays (2/2)

Highly simplified example.
Assume CPU has no registers and cache is 4 words using LRU.

```
int fibonacci2(int n) {
    if (n < 1) {
        return 0;
    }
    if (n < 2) {
        return 1;
    }

    int t1 = 0, t2 = 1;
    for (int i = 1; i < n; ++i) {
        t2 = t1 + t2;
        t1 = t2 - t1;
    }
    return t2;
}
```

Cache Contents				Inst.	M/H
n				`start`	-
n				`n < 1; n < 2`	H
t1	n			`t1 = 0`	M
t2	t1	n		`t2 = 1`	M
i	n	t2	t1	`i = 0; i < n`	M; H
t2	t1	i	n	`t2 = t1 + t2`	H
t1	t2	i	n	`t1 = t2 - t1`	H
i	t1	t2	n	`++i`	H
i	n	t1	t2	`i < n`	H
t2	t1	i	n	`t2 = t1 + t2`	H
t1	t2	i	n	`t1 = t2 - t1`	H
⋮					

(1) No excess variables in loop; everything in cache.
(2) Local variables don't ruin caller's cache in degenerative cases (`n` already in cache of caller).