Recitation 6: Cache Access Patterns

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15213 Section A
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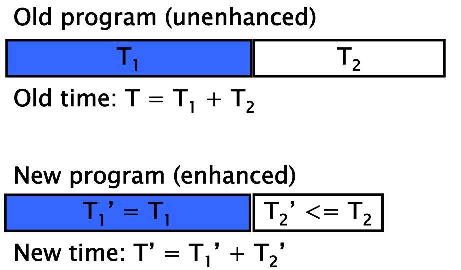
- Office hours:
  - NSH 2504 (lab) / 2507 (conference room)
  - Wednesday 5-6
- Lab 4
  - due Thursday, 24 Oct @ 11:59pm

Today's Plan

- Optimization
  - Amdahl's law
- Cache Access Patterns
  - Practice problems 6.4, 6.15-17
- Lab 4
  - Horner's Rule, including naïve code

Amdahl's law



T_1 = time that can NOT be enhanced.

T_2 = time that can be enhanced.

T_2' = time after the enhancement.

Speedup: $S_{overall} = T / T'$

Key idea: Amdahl's law quantifies the general notion of diminishing returns. It applies to any activity, not just computer programs.

Example: Amdahl's law

- You plan to visit a friend in Normandy France and must decide whether it is worth it to take the Concorde SST ($3,100) or a 747 ($1,021) from NY to Paris, assuming it will take 4 hours Pgh to NY and 4 hours Paris to Normandy.

	time NY->Paris	total trip time	speedup over 747
747	8.5 hours	16.5 hours	1
SST	3.75 hours	11.75 hours	1.4

- Taking the SST (which is 2.2 times faster) speeds up the overall trip by only a factor of 1.4!

Amdahl's law (cont)

- Trip example: Suppose that for the New York to Paris leg, we now consider the possibility of taking a rocket ship (15 minutes) or a handy rip in the fabric of space-time (0 minutes):

	time NY->Paris	total trip time	speedup over 747
747	8.5 hours	16.5 hours	1
SST	3.75 hours	11.75 hours	1.4
rocket	0.25 hours	8.25 hours	2.0
rip	0.0 hours	8 hours	2.1

Moral: It is hard to speed up a program.
Moral++ : It is easy to make premature optimizations.

Locality

- **Temporal locality**: a memory location that is referenced once is likely to be *reference again multiple times* in the near future
- **Spatial locality**: if a memory location is referenced once, then the program is likely to *reference a nearby memory location* in the near future

Practice Problem 6.4

```
int summary3d(int a[N][N][N])
{
    int i, j, k, sum = 0;
    for (i = 0; i < N; i++) {
        for (j = 0; k < N; j++ ) {
            for (k = 0; k < N; k++ ) {
                sum += a[k][i][j];
            }
        }
    }
    return sum;
}
```

Answer

```
int summary3d(int a[N][N][N])
{
    int i, j, k, sum = 0;
    for (k = 0; k < N; k++) {
        for (i = 0; i < N; i++ ) {
            for (j = 0; j < N; j++ ) {
                sum += a[k][i][j];
            }
        }
    }
    return sum;
}
```

Cache Access Patterns

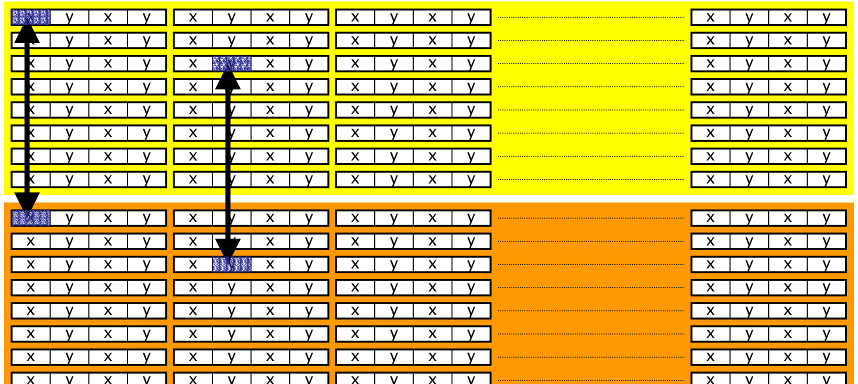
- Spend the next fifteen minutes working on Practice Problems 6.15-17
- Handout is a photocopy from the text

Practice Problem 6.15-17

- **`sizeof(algae_position) = 8`**
- Each block (16 bytes) holds two **`algae_position`** structures
- The 16×16 array requires 2048 bytes of memory
  - Twice the size of the 1024 byte cache

Practice Problem 6.15-17

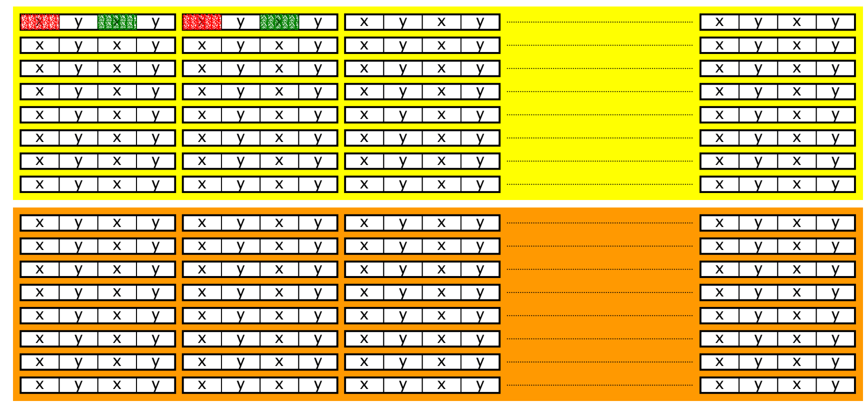
- Rows: 16 items (8 blocks, 128 bytes)
- Columns: 16 items
- Yellow block: 1k; Orange block 1k



6.15: Row major access pattern

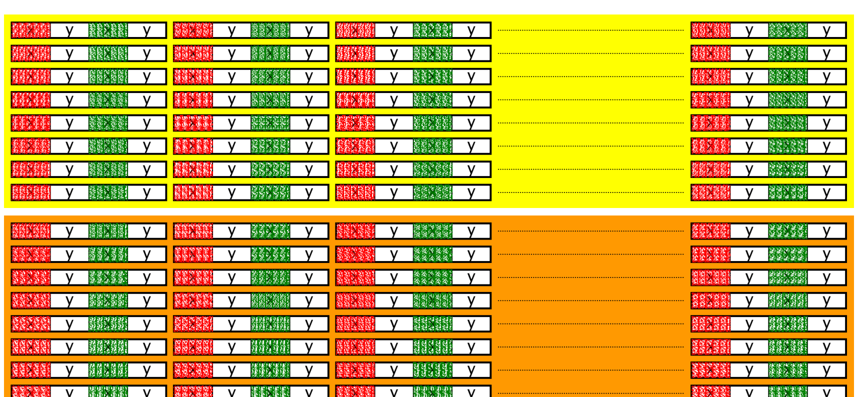
6.15: Stride of 2 words

- First loop, accessing just x's



6.15: Stride of 2 words

- First loop, accessing just x's



6.15: Stride of 2 words

- Second loop, accessing just the y's
- Same miss pattern because accessing the orange area flushed blocks from the yellow area

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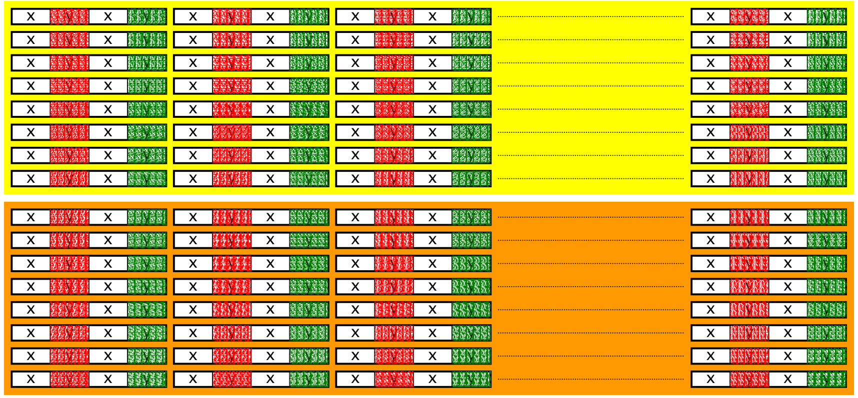
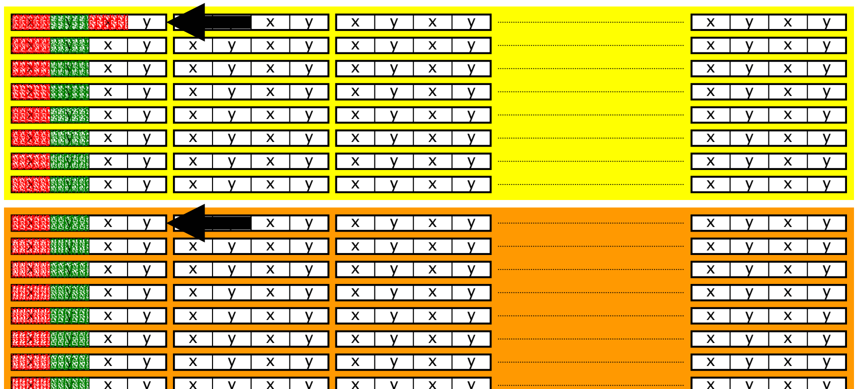


Answers to 6.15

- A: 512
  - 2 for each of 256 array elements
- B: 256
  - Every other array element experiences a miss
- C: 50%

Column major access pattern

New access removes first cache line contents before its were used



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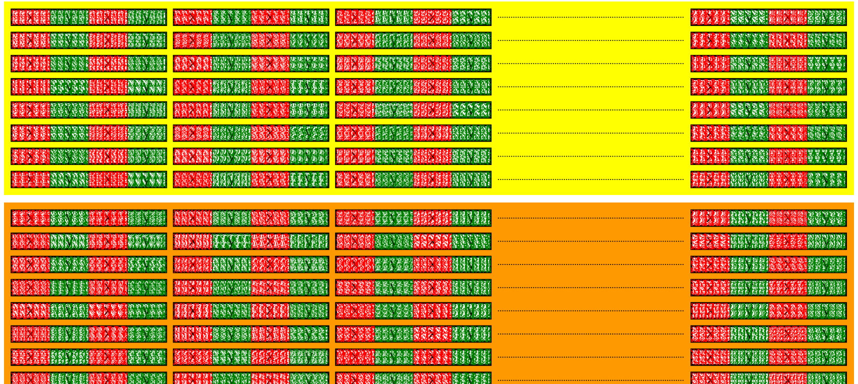
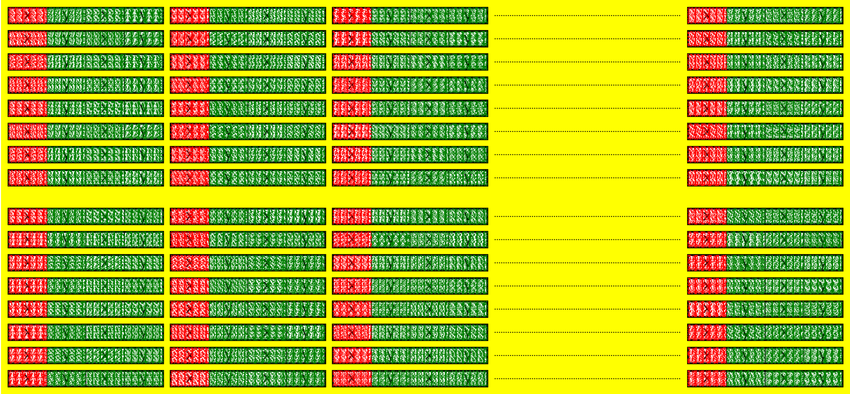


Answers to 6.16

- A: 512
- B: 256
- C: 50%

Column major access pattern

No misses on second access to each block, because the entire array fits in the cache.

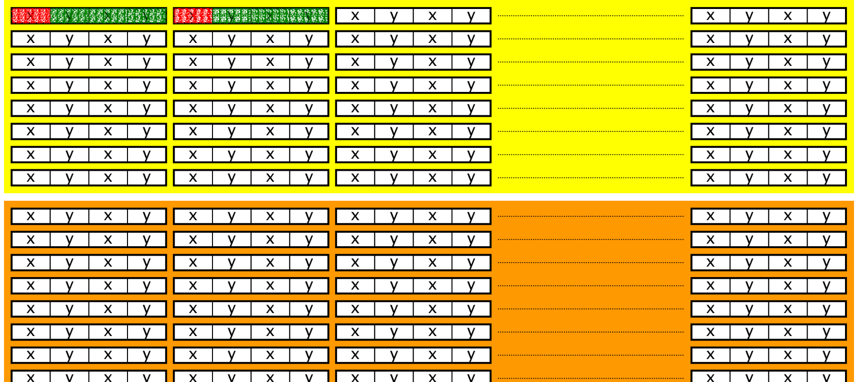


Answers to 6.16

- A: 512
- B: 256
- C: 50%
- D: 25%

Stride of 1 word

- Access both x and y in row major order



Stride of 1 word

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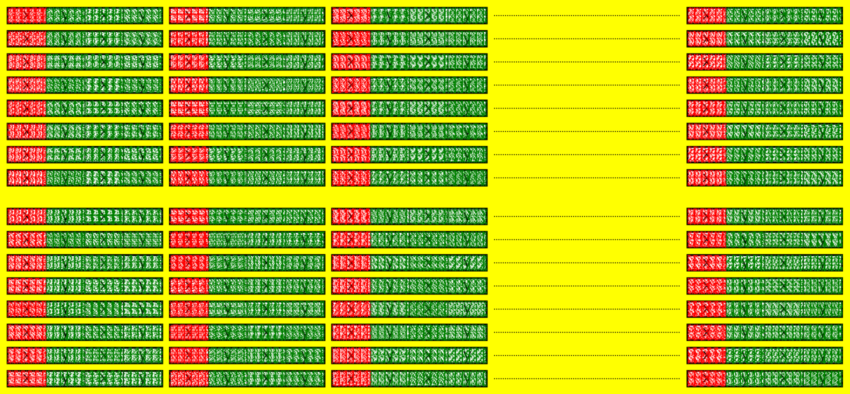

Answers to 6.17

- A: 512
- B: 128
  - All are compulsory misses
- C: 25%
- D: 25%
  - Cache size does not matter since all misses are compulsory
  - Though the block size does matter

Lab 4: Horner's Rule

Polynomial of degree d (d+1 coefficients)

$$P(x)=a_0+a_1x+a_2x^2+\cdots+a_dx^d$$

$$P(x)=a_0+(a_1+(a_2+(\cdots+(a_{d-1}+a_dx)x\cdots)x)x)x$$

Naïve code for Horner's Rule

```
/* Horner's rule */
int poly_evalh(int *a, int degree, int x)
{
    int result = a[degree];
    int i;
    for (i = degree-1; i >= 0; i--)
        result = result*x+a[i];
    return result;
}
```