ETH Zürich
Chair of Software Engineering

Concepts of Concurrent Computation

Bertrand Meyer
Sebastian Nanz

Lecture 1: Welcome and introduction

Practical Details

- Schedule
  - Course: Tuesday 10-12, RZ F21
  - Exercise: Tuesday 12-13, RZ F21
- Course page
  - Check it at least once a week: http://se.inf.ethz.ch/teaching/2011-F/CCC-0268/
  - Lecturers
  - Prof. Dr. Bertrand Meyer
  - Dr. Sebastian Nanz
- Assistants
  - Benjamin Morandi
  - Scott West

Grading

- Exam 50%
    - Will be held at the end of the semester (not in the semester break).
    - Exam date: May 31, 2011 during the usual lecture hours
- Project 50%

Course description (from catalog)

- This course explores the connections between the object oriented and concurrent programming paradigms, discussing the problems that arise in the process of attempting to merge them
- It reviews the main existing approaches to concurrent O-O computation, including both widely used libraries for multi-threading in Java and .NET and more theoretical frameworks, with a particular emphasis on the SCOOP model
- It also provides some of the formal background for discussing the correctness of concurrent O-O applications

Purpose of the course

- To give you a practical grasp of the excitement and difficulties of building modern concurrent applications
- To expose you to newer forms of concurrency
- To study how the object-oriented paradigm transposes to concurrent settings, and how it can help address concurrency issues
- To introduce you to the main concurrency approaches and give you an idea of their strength and weaknesses
- To present some of the concurrency calculi
- To study in depth one particular approach: SCOOP
- To enable you to get a concrete grasp of the issues and solutions through a course project

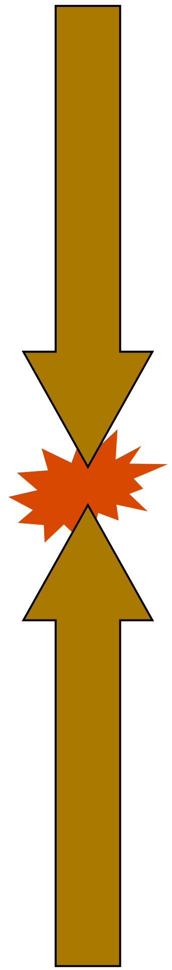
Two sides of the same coin

"Classic" part

- Survey of classic and modern approaches
- Explains historical evolution
- Illustrates problems and solutions e.g., Java

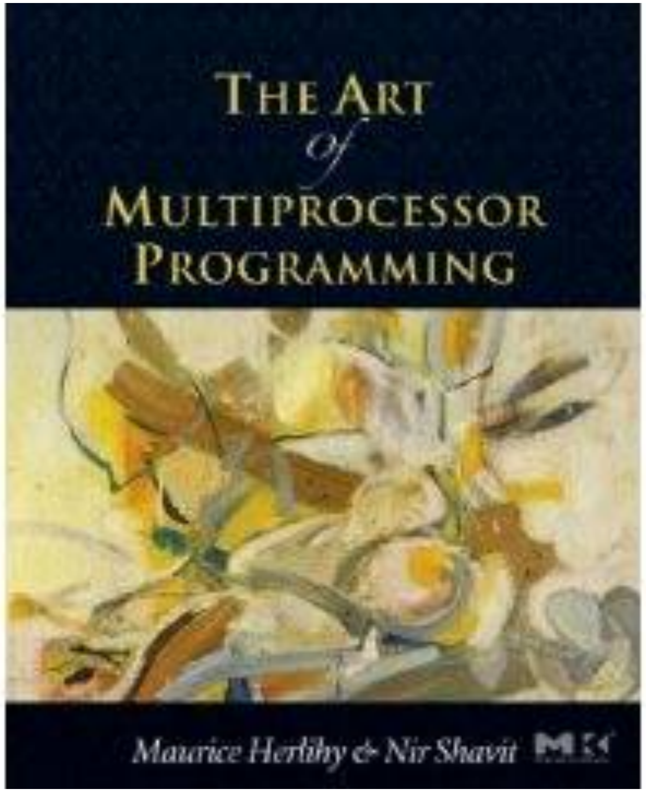
SCOOP part

- The "object lesson"
- High-level support for concurrency
- Concurrency solution integrated with an OO programming language, i.e., Eiffel
- Starts from object-oriented programming as a given, adds concurrency



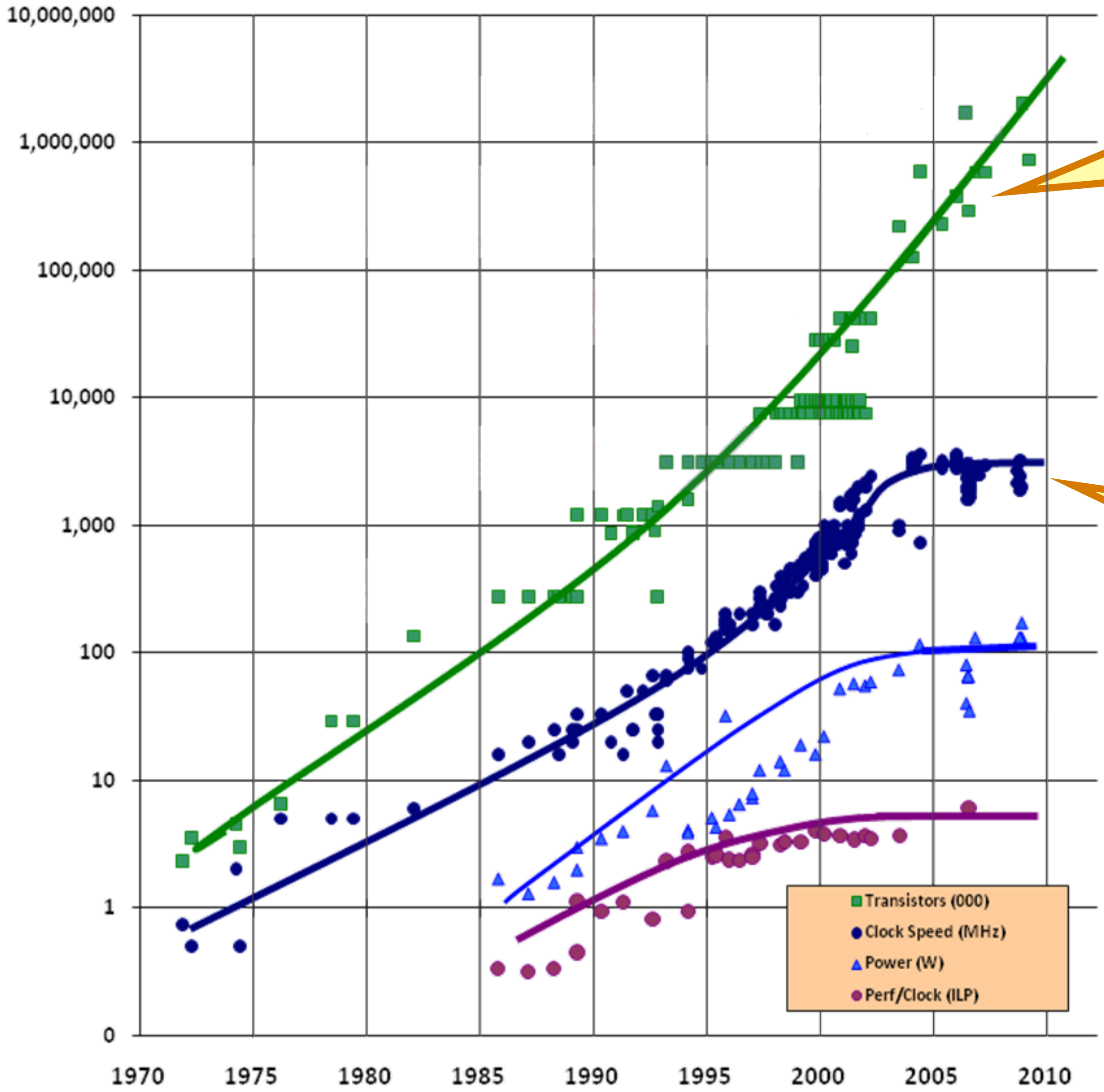
Concurrency: benefits and challenges

Material (slightly adapted) from



The Art of Multiprocessor Programming
by Maurice Herlihy & Nir Shavit

Moore's Law

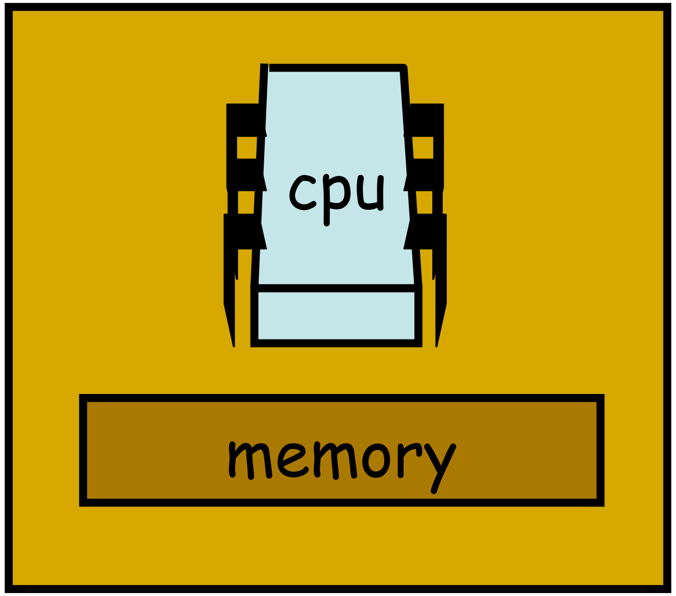


Transistor count still rising

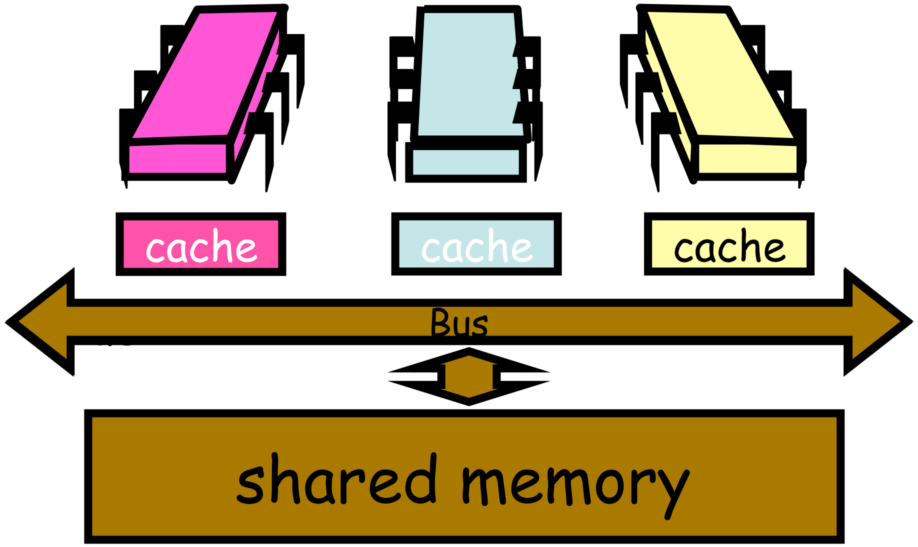
Clock speed flattening sharply

Source: Intel

Uniprocessor

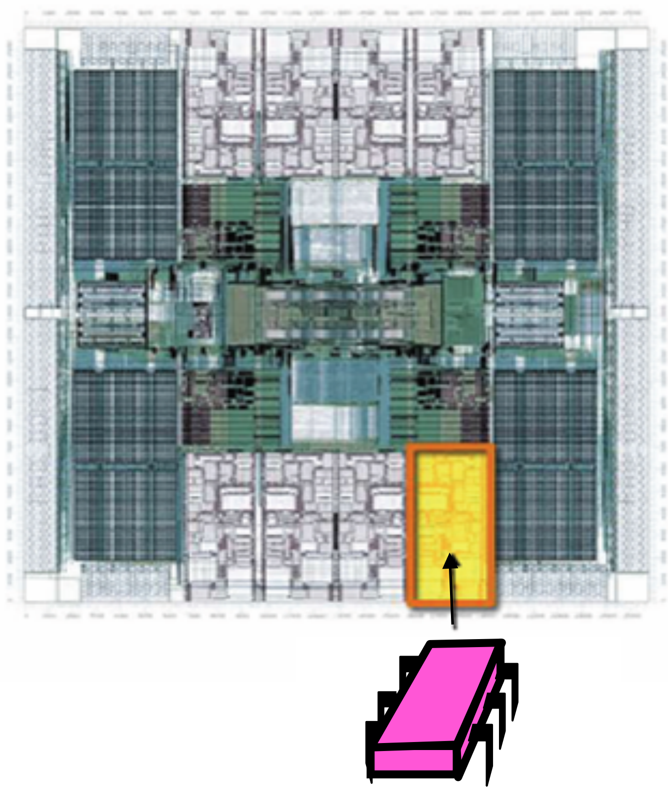


Shared Memory Multiprocessor (SMP)



Multicore Processor (CMP)

All on the same chip



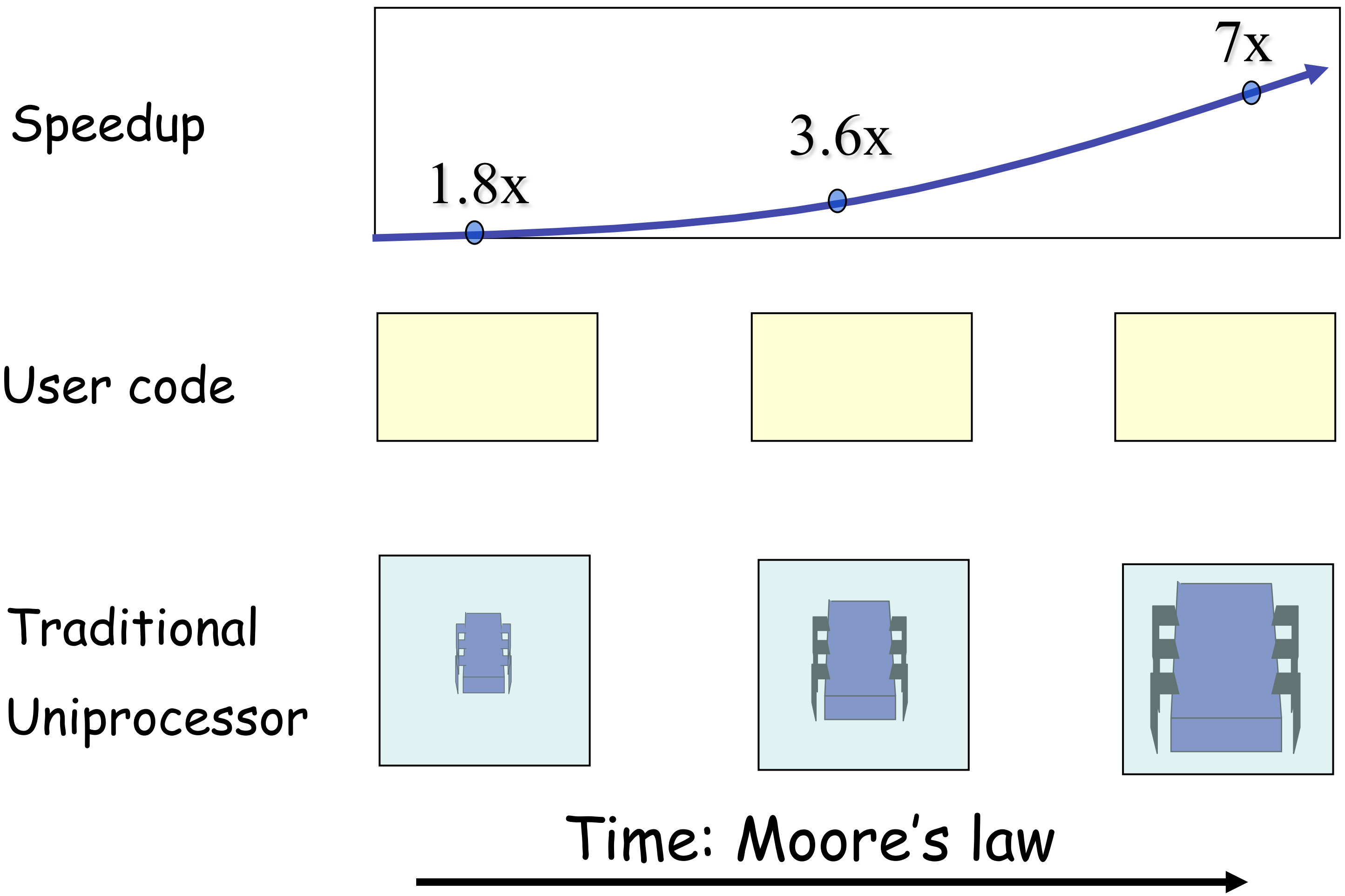
Sun T2000

Niagara

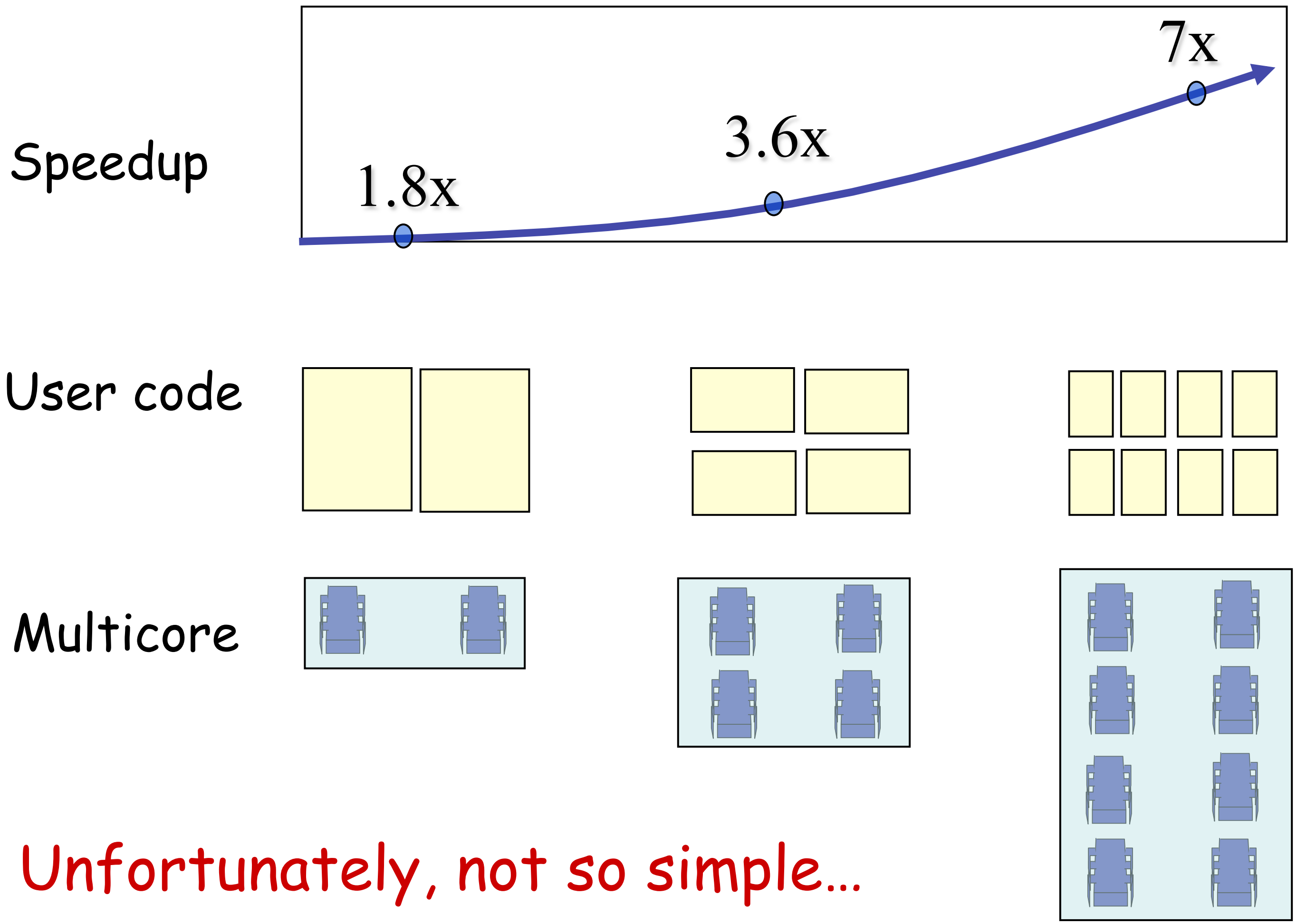
Why do we care about multicore processors?

- Time no longer cures software bloat
  - The "free ride" is over
- When you double your program's path length
  - You can't just wait 6 months
  - Your software must somehow exploit twice as much concurrency

Traditional scaling process

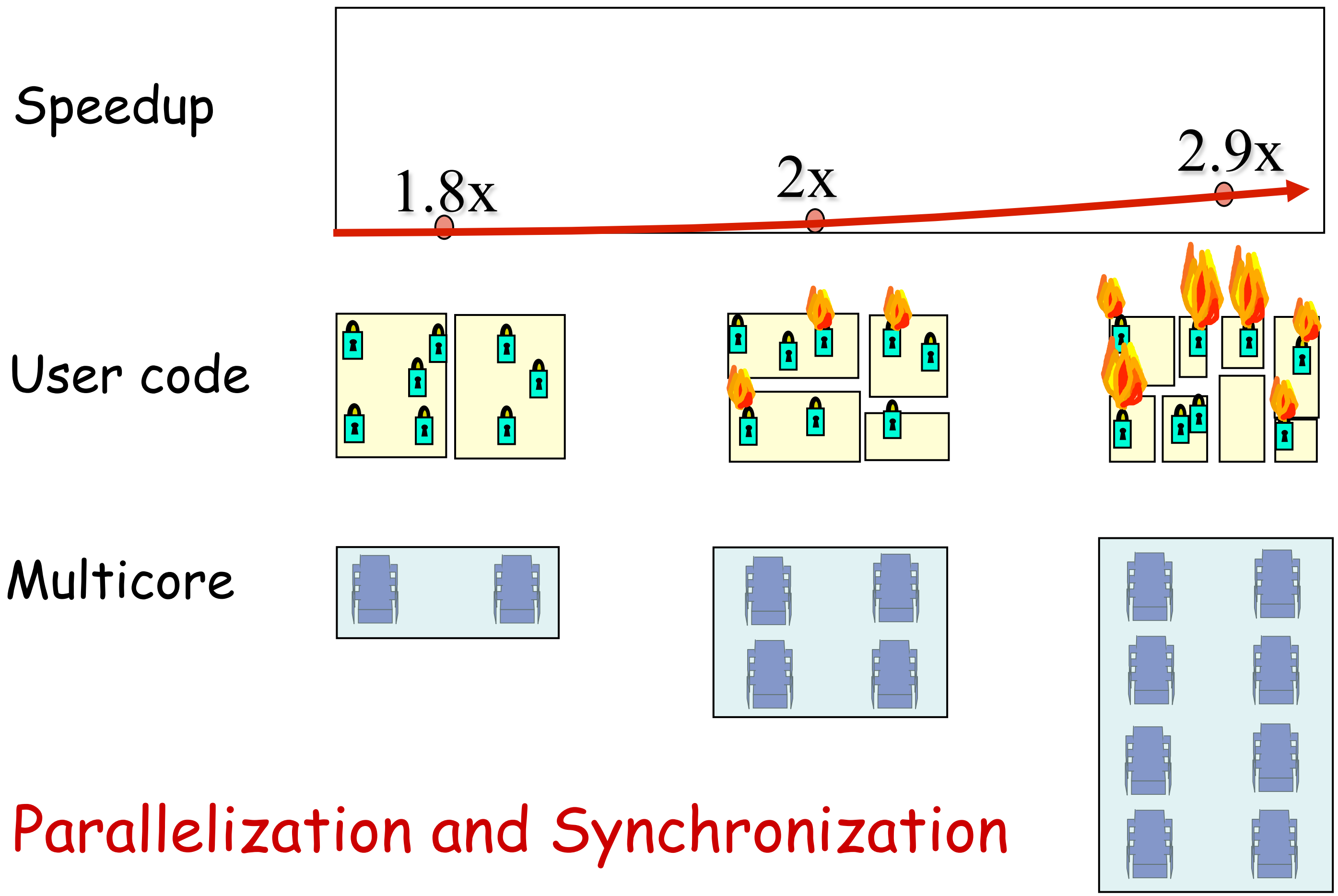


Multicore scaling process: the hope



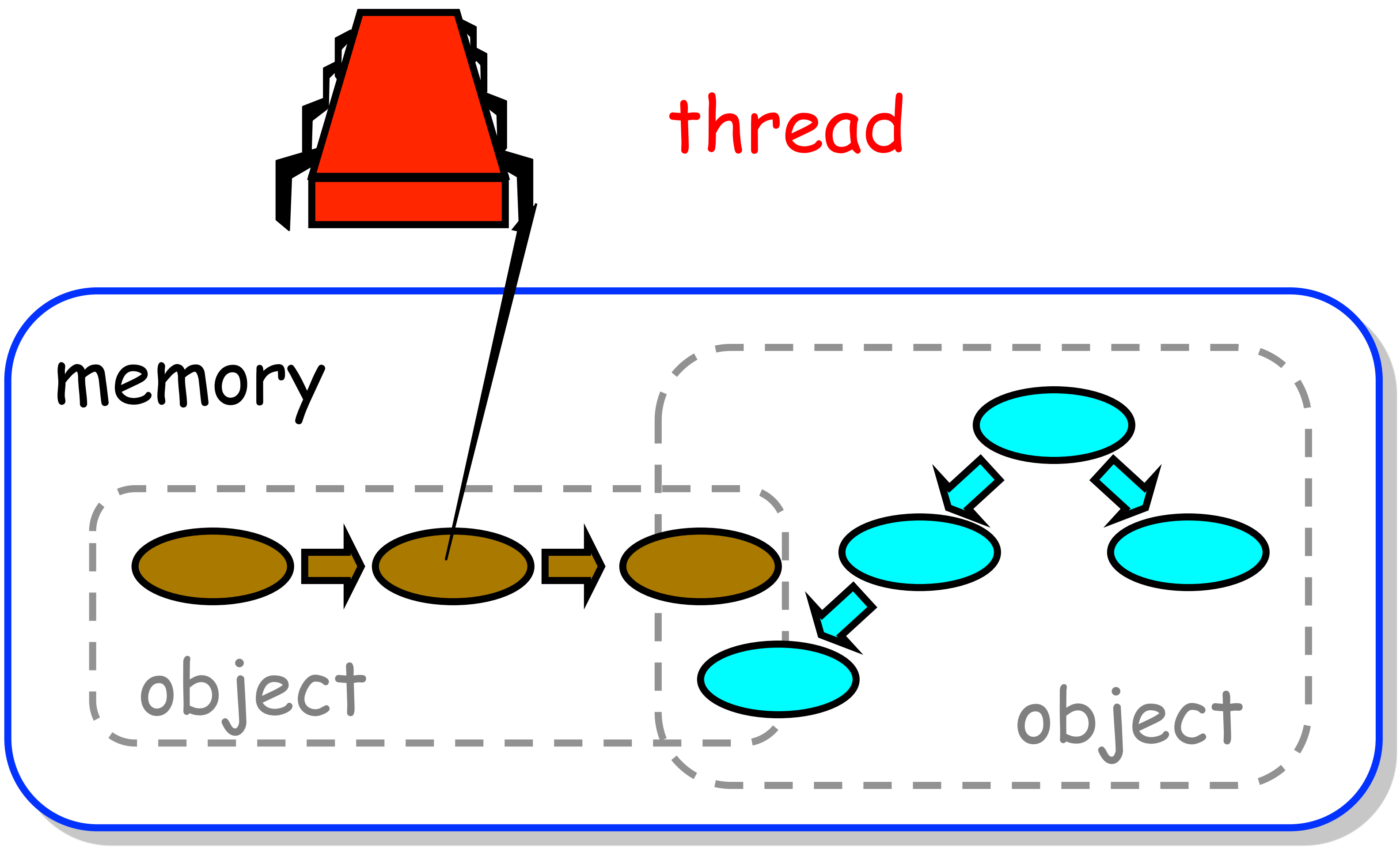
Unfortunately, not so simple…

Real scaling process

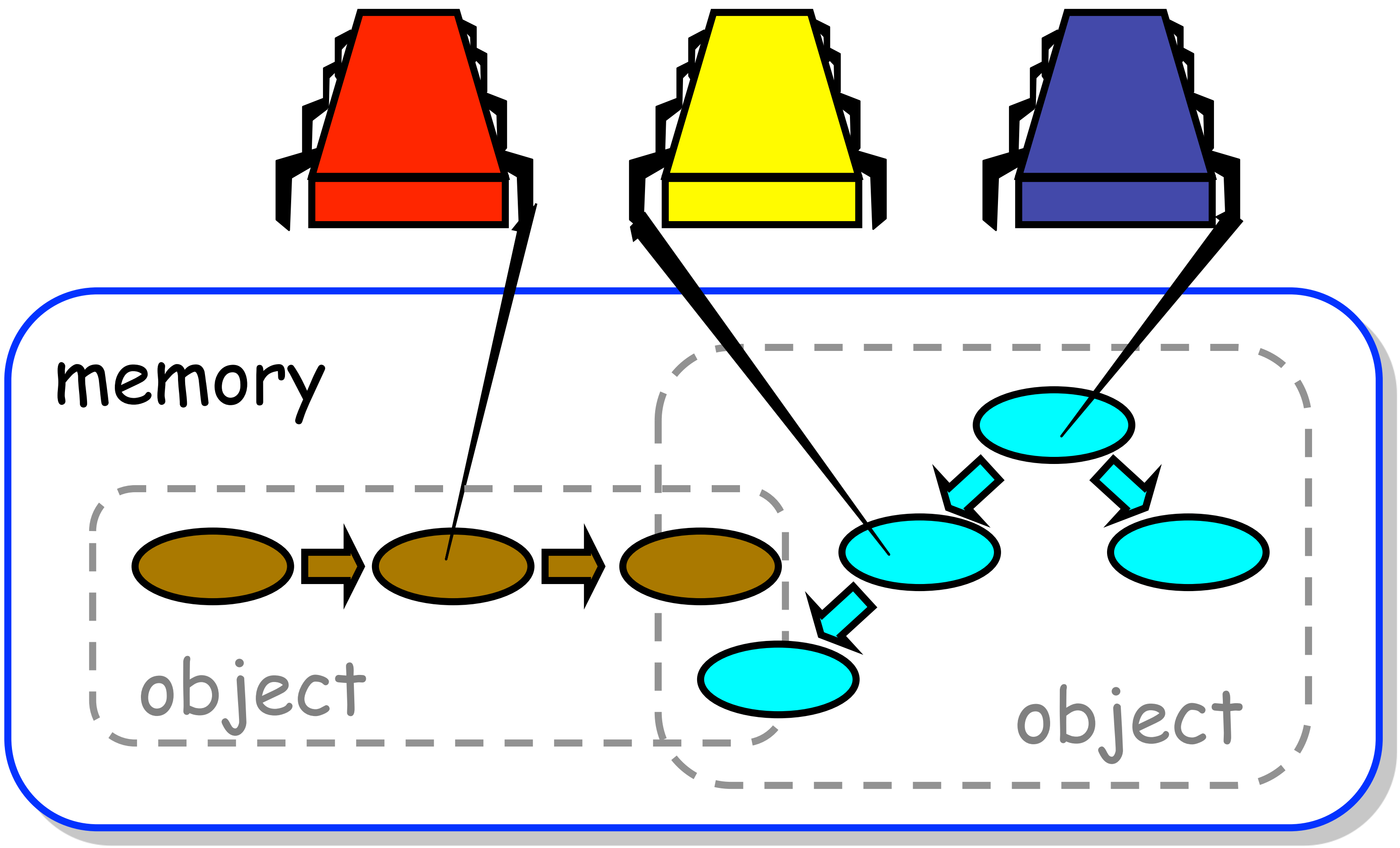


Parallelization and Synchronization require great care…

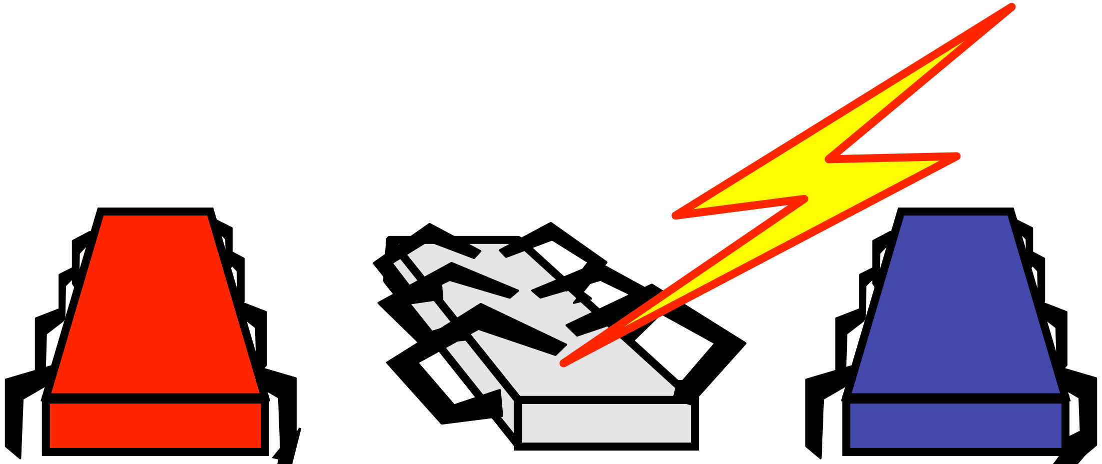
Sequential computation



Concurrent computation



Asynchrony



Sudden unpredictable delays

- Cache misses (short)
- Page faults (long)
- Scheduling quantum used up (really long)

Model summary

- Multiple threads
    - Sometimes called processes
- Single shared memory
- Objects live in memory
- Unpredictable asynchronous delays

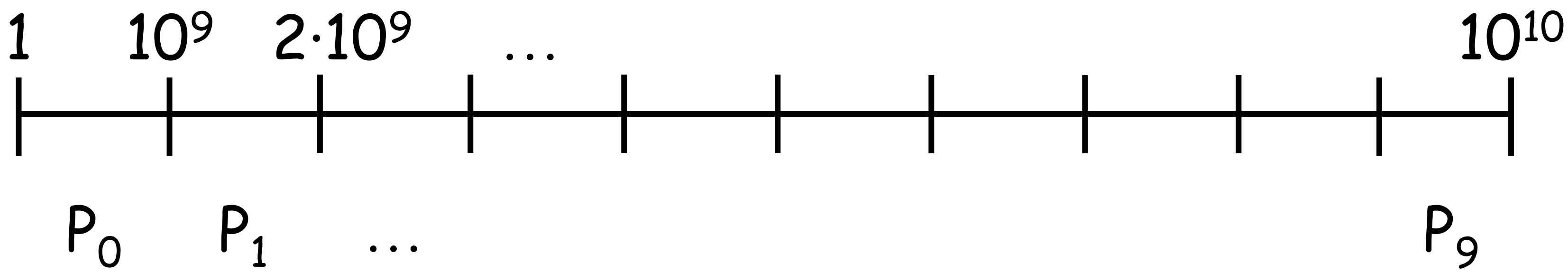
Concurrency jargon

- Hardware
  - Processors
- Software
  - Threads, processes
- Sometimes OK to confuse them, sometimes not.

Example: parallel primality testing

- Challenge
  - Print primes from 1 to 10^{10}
- Given
  - Ten-processor multiprocessor
  - One thread per processor
- Goal
  - Get ten-fold speedup (or close)

Load balancing



- Split the work evenly
- Each thread tests range of 10^9

Procedure for thread i

```
void primePrint {
  int i = ThreadID.get(); // IDs in {0..9}
  for (j = i*10^9+1, j<(i+1)*10^9; j++) {
    if (isPrime(j))
      print(j);
  }
}
```

Issues

- Higher ranges have fewer primes
- Yet larger numbers harder to test
- Thread workloads
  - Uneven
  - Hard to predict
- Need dynamic load balancing

rejected

Amdahl's Law

$$\textit{speedup} = \frac{\text{old execution time}}{\text{new execution time}}$$

…of computation given n CPUs instead of 1

Amdahl's Law

Sequential fraction

Parallel fraction

$$speedup = \frac{1}{\boxed{1 - p} + \frac{\boxed{p}}{\boxed{n}}}$$

Number of processors

Example

- Ten processors
- 60% concurrent, 40% sequential
- How close to 10-fold speedup?

$$speedup = 2.17 = \frac{1}{1 - 0.6 + \frac{0.6}{10}}$$

Example

- Ten processors
- 80% concurrent, 20% sequential
- How close to 10-fold speedup?

$$speedup = 3.57 = \frac{1}{1 - 0.8 + \frac{0.8}{10}}$$

Example

- Ten processors
- 90% concurrent, 10% sequential
- How close to 10-fold speedup?

$$speedup = 5.26 = \frac{1}{1 - 0.9 + \frac{0.9}{10}}$$

Example

- Ten processors
- 99% concurrent, 1% sequential
- How close to 10-fold speedup?

$$speedup = 9.17 = \frac{1}{1 - 0.99 + \frac{0.99}{10}}$$

The moral

- Making good use of our multiple processors (cores) means finding ways to effectively parallelize our code
  - Minimize sequential parts
  - Reduce idle time in which threads **wait** without doing something useful.

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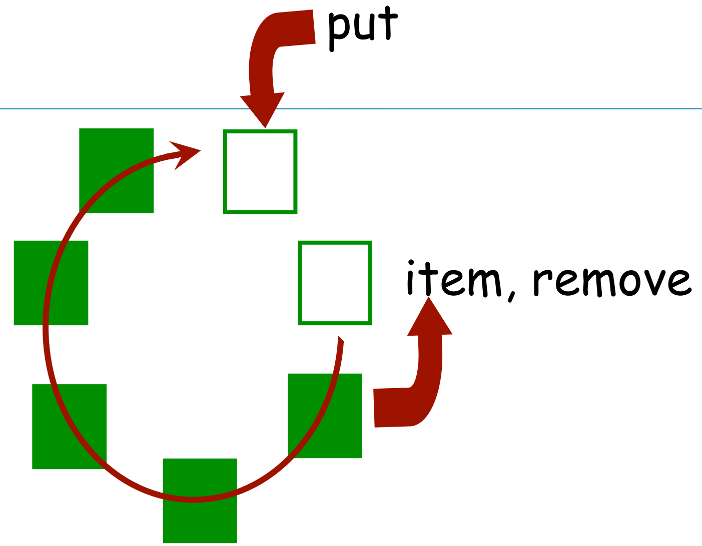
SCOOP Taster




```
put (b: QUEUE [G]; v: G)
        -- Store v into b.
    require
        not b.is_full
    do
        ...
    ensure
        not b.is_empty
    end
```

```
my_queue : QUEUE [T]
...

if not my_queue.is_full then


        put (my_queue, t)
end
```

The issue

Concurrency everywhere:

- Multithreading
- Multitasking
- Networking, Web services, Internet
- Multicore

Can we bring concurrent programming
to the same level
of abstraction and convenience
as sequential programming?

Previous advances in programming

	"Structured programming"	"Object technology"
Use higher-level abstractions	✓	✓
Helps avoid bugs	✓	✓
Transfers tasks to implementation	✓	✓
Lets you do stuff you couldn't before	NO	✓
Removes restrictions	NO	✓
Adds restrictions	✓	✓
Has well-understood math basis	✓	✓
Doesn't require understanding that basis	✓	✓
Permits less operational reasoning	✓	✓

Then and now

Sequential programming:

Used to be messy

Still hard but key improvements:

- Structured programming
- Data abstraction & object technology
- Design by Contract
- Genericity, multiple inheritance
- Architectural techniques

Concurrent programming:

Used to be messy

Still messy

Example: threading models in most popular approaches

Development level: sixties/ seventies

Only understandable through operational reasoning

The chasm

Theoretical models, process calculi… Elegant theoretical basis, but

- Little connection with practice (some exceptions, e.g. BPEL)
- Handle concurrency aspects only

Practice of concurrent & multithreaded programming

- Little influenced by above
- Low-level, e.g. semaphores
- Poorly connected with rest of programming model

Wrong (in my opinion) assumptions

"*Objects are naturally concurrent*" (Milner)

- Many attempts, often based on "Active objects" (a self-contradictory notion)
- Lead to artificial issue of "Inheritance anomaly"

"Concurrency is the basic scheme, sequential programming a special case " (many)

- Correct in principle, but in practice we understand sequential best

SCOOP mechanism

Simple Concurrent Object-Oriented Programming

Evolved through last decade; *CACM* (1993) and chap. 30 of *Object-Oriented Software Construction*, 2nd edition, 1997

Implemented at ETH, integrated into EiffelStudio

Current state is described in Piotr Nienaltowski's 2007 ETH PhD dissertation

Dining philosophers

```
class PHILOSOPHER inherit
      PROCESS
            rename
                  setup as getup
            redefine step end

feature {BUTLER}
      step
            do
                  think ;   eat (left, right)
            end

      eat (l, r: separate FORK)
                  -- Eat, having grabbed l and r.
            do … end
end
```