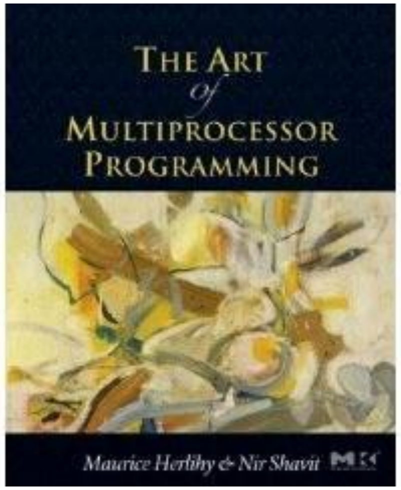
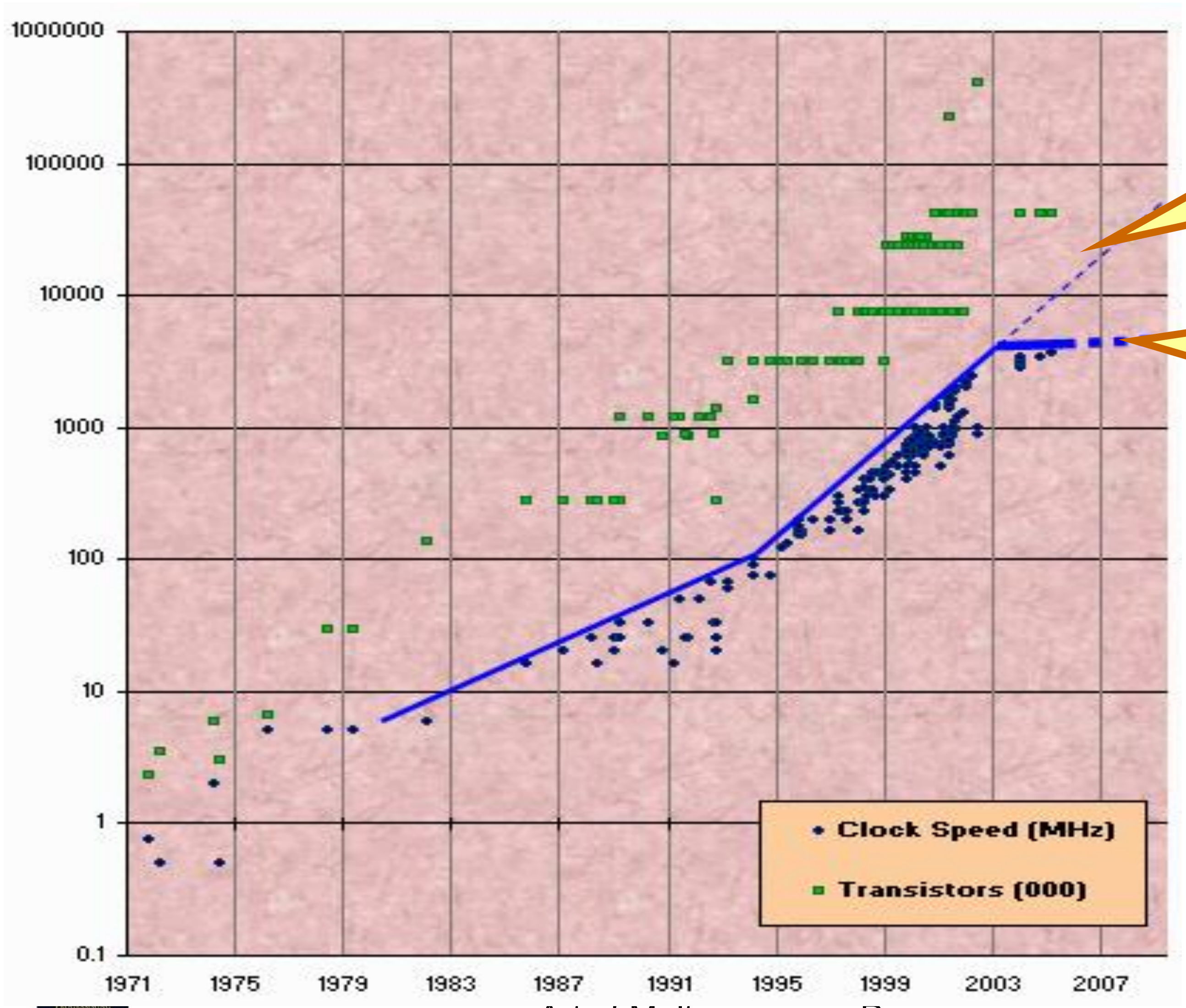
Introduction


THE ART of MULTIPROCESSOR PROGRAMMING
Maurice Herlihy & Nir Shavit
MK

Companion slides for
The Art of Multiprocessor Programming
by Maurice Herlihy & Nir Shavit

Moore's Law

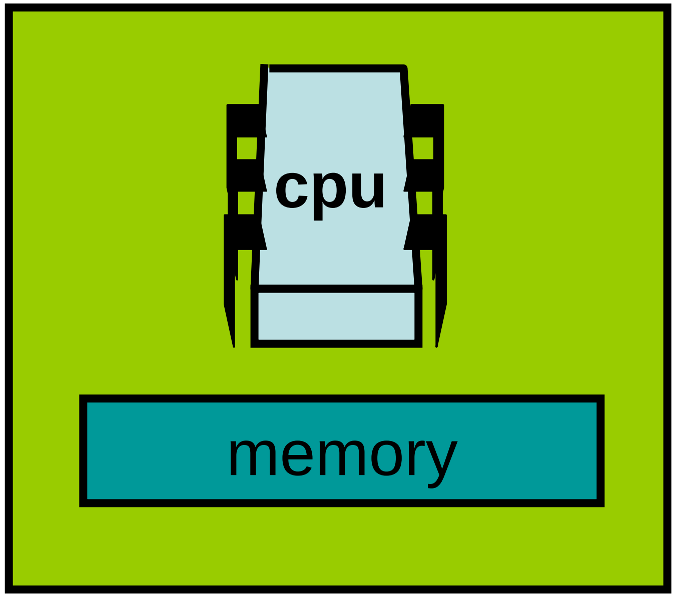


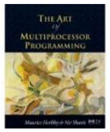
Transistor count still rising

Clock speed flattening sharply

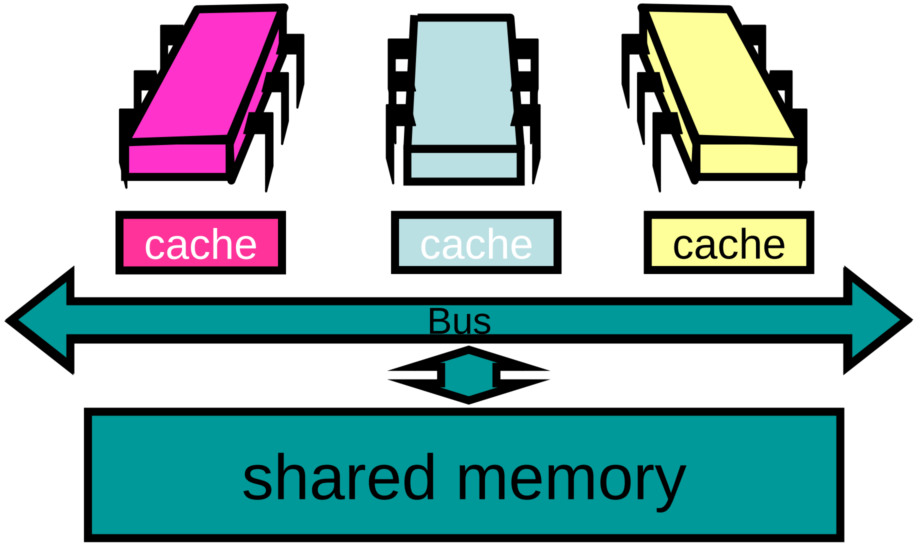
Moore's Law (in practice)

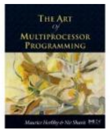
Nearly Extinct: the Uniprocesor





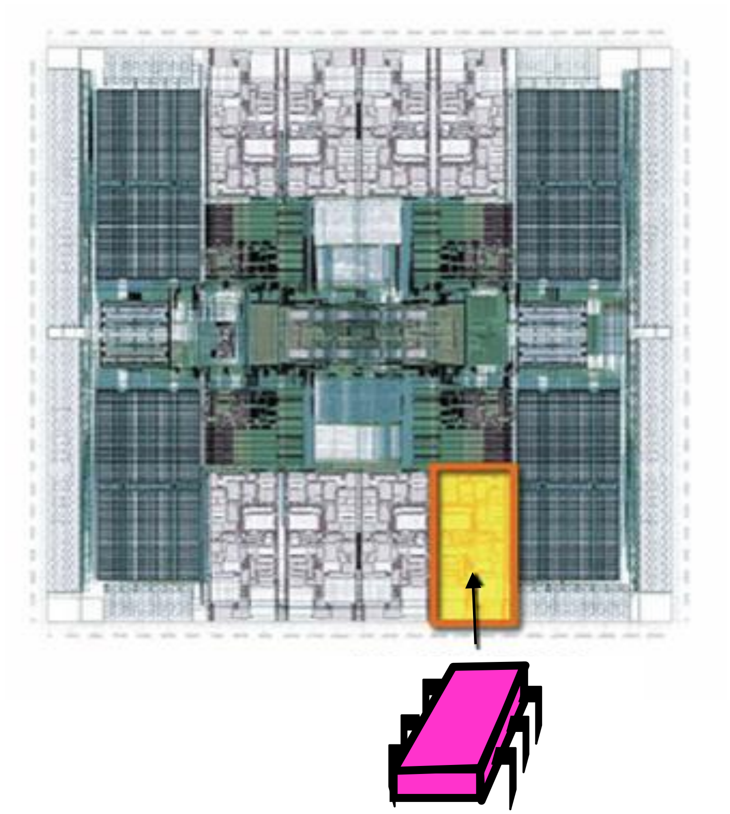
Endangered: The Shared Memory Multiprocessor (SMP)



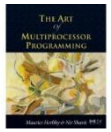


The New Boss: The Multicore Processor (CMP)

All on the same chip

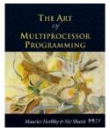


Sun T2000 Niagara



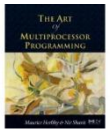
Why do we care?

- We want as much as possible to execute concurrently (in parallel)
- A larger sequential part implies reduced performance
- Amdahl’s law: this relation is not linear…



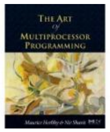
Amdahl's Law

$$\text{Speedup} = \frac{1\text{-thread execution time}}{n\text{-thread execution time}}$$



Amdahl's Law

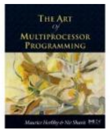
$$\textbf{Speedup=} \quad \frac{1}{1 \text{¡} \; p + \frac{p}{n}}$$



Amdahl's Law

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

Parallel fraction

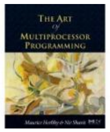


Amdahl’s Law

Parallel fraction

Speedup= $$\frac{1}{1 - p + \frac{p}{n}}$$

Number of threads



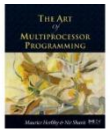
Amdahl's Law

Sequential fraction

Parallel fraction

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

Number of threads

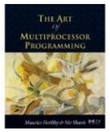


Amdahl’s Law in Practice

Bad synchronization ruins everything

Example

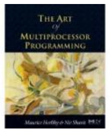
- Ten processors
- 60% concurrent, 40% sequential
- How close to 10-fold speedup?



Example

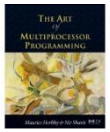
- Ten processors
- 60% concurrent, 40% sequential
- How close to 10-fold speedup?

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



Example

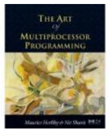
- Ten processors
- 80% concurrent, 20% sequential
- How close to 10-fold speedup?



Example

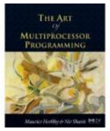
- Ten processors
- 80% concurrent, 20% sequential
- How close to 10-fold speedup?

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



Example

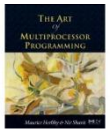
- Ten processors
- 90% concurrent, 10% sequential
- How close to 10-fold speedup?



Example

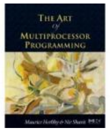
- Ten processors
- 90% concurrent, 10% sequential
- How close to 10-fold speedup?

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



Example

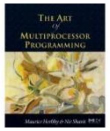
- Ten processors
- 99% concurrent, 01% sequential
- How close to 10-fold speedup?



Example

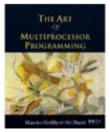
- Ten processors
- 99% concurrent, 01% sequential
- How close to 10-fold speedup?

Speedup = 9.17= $\dfrac{1}{1-0.99+\dfrac{0.99}{10}}$



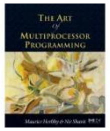
Concurrent Objects

- What is a concurrent object?
  - How do we **describe** one?
  - How do we **implement** one?
  - How do we **tell if we're right**?



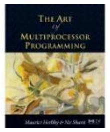
Sequential Objects

- Each object has a ***state***
  - Usually given by a set of ***fields***
  - Queue example: sequence of items
- Each object has a set of ***methods***
  - Only way to manipulate state
  - Queue example: **enq** and **deq** methods



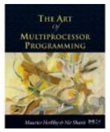
Sequential Specifications

- If (precondition)
  - the object is in such-and-such a state
  - before you call the method,
- Then (postcondition)
  - the method will return a particular value
  - or throw a particular exception.
- and (postcondition, con't)
  - the object will be in some other state
  - when the method returns,



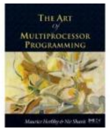
Pre and PostConditions for Dequeue

- Precondition:
  - Queue is non-empty
- Postcondition:
  - Returns first item in queue
- Postcondition:
  - Removes first item in queue



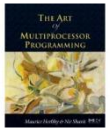
Pre and PostConditions for Dequeue

- Precondition:
  - Queue is empty
- Postcondition:
  - Throws Empty exception
- Postcondition:
  - Queue state unchanged



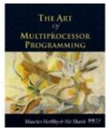
Sequential Specifications

- Interactions among methods captured by side-effects on object state
  - State meaningful between method calls
- Documentation size linear in number of methods
  - Each method described in isolation
- Can add new methods
  - Without changing descriptions of old methods

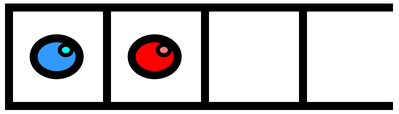


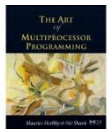
What About Concurrent Specifications ?

- Methods?
- Documentation?
- Adding new methods?



Methods Take Time





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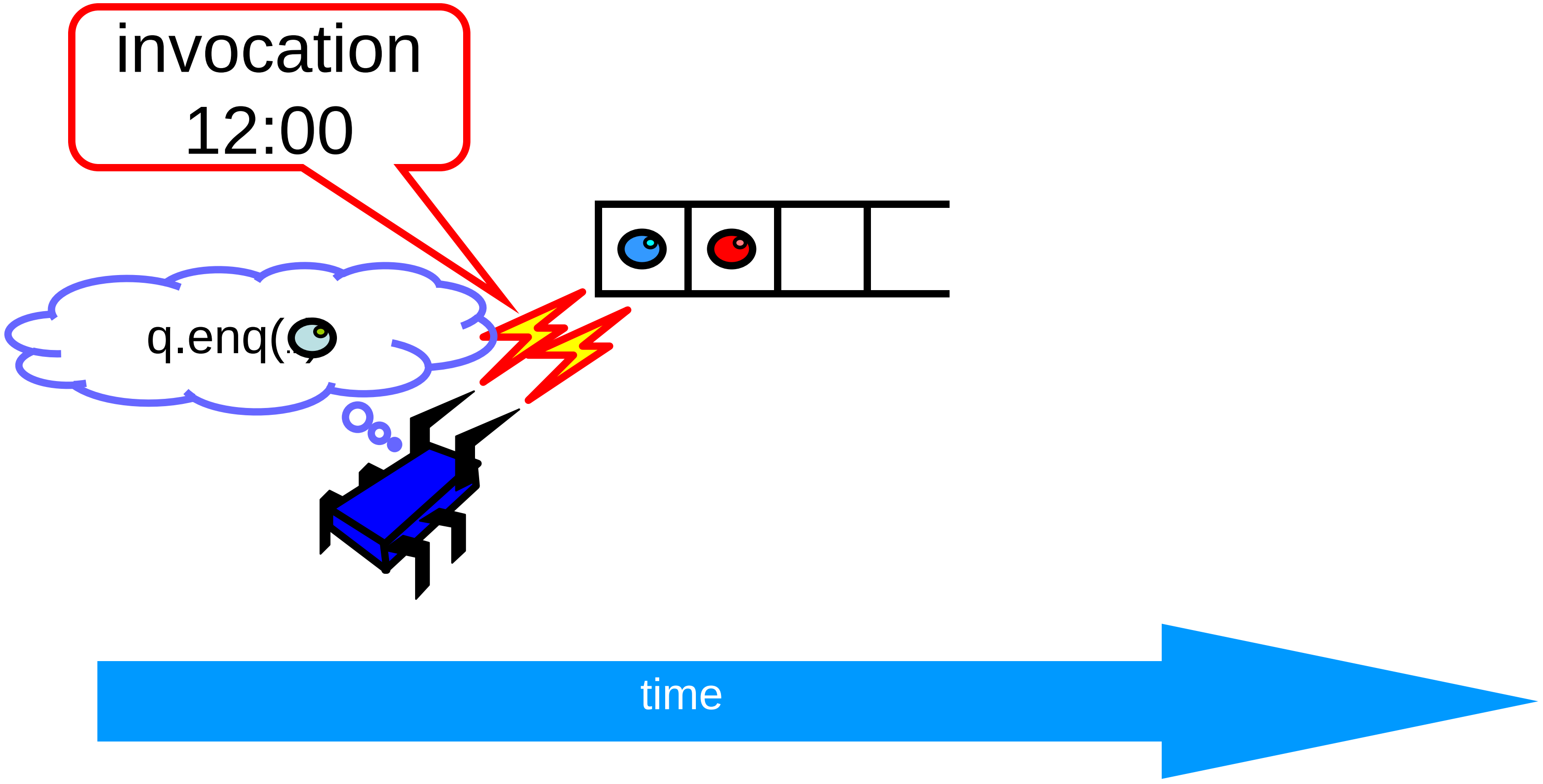

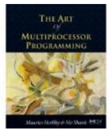

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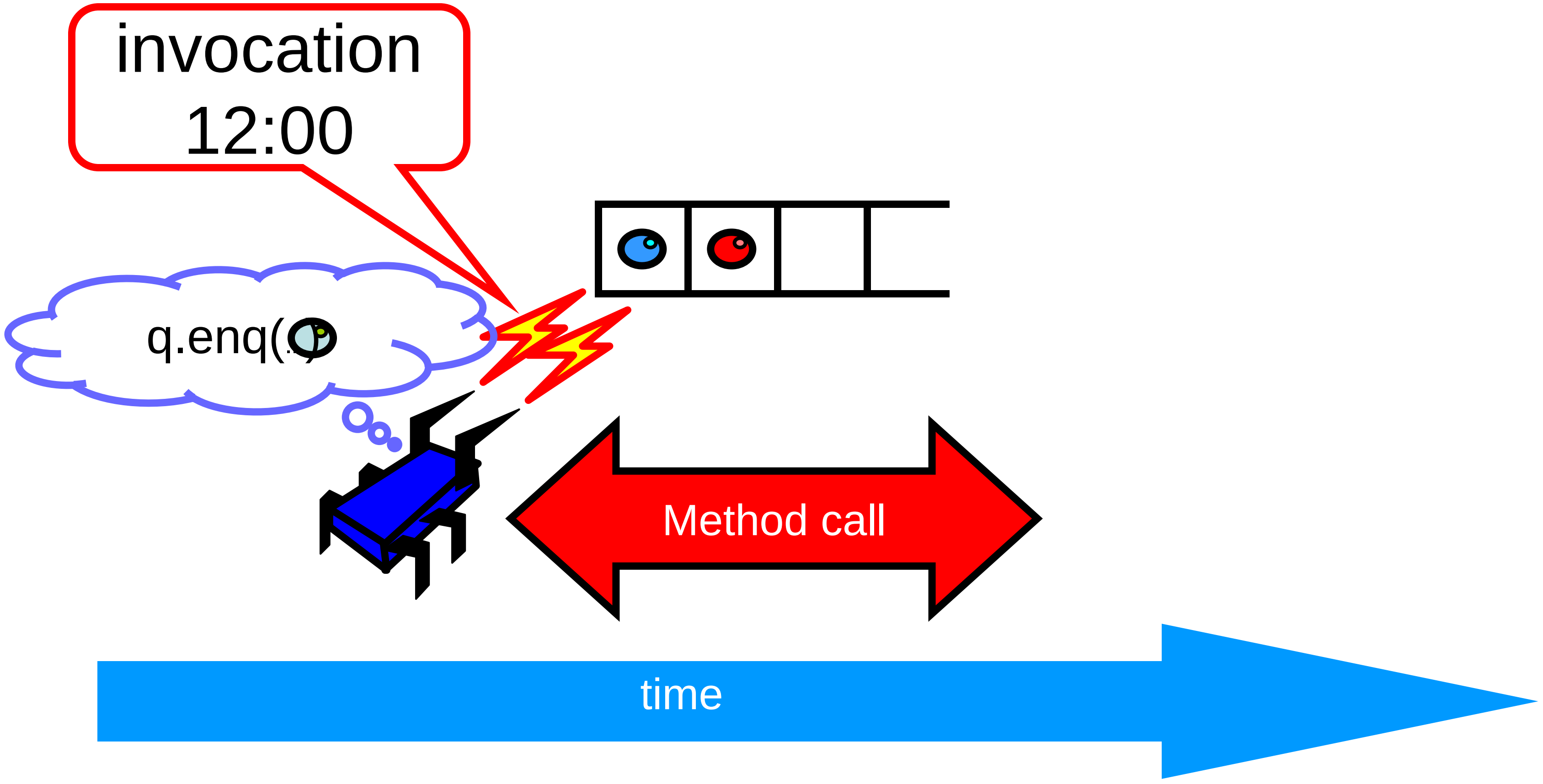

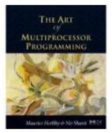

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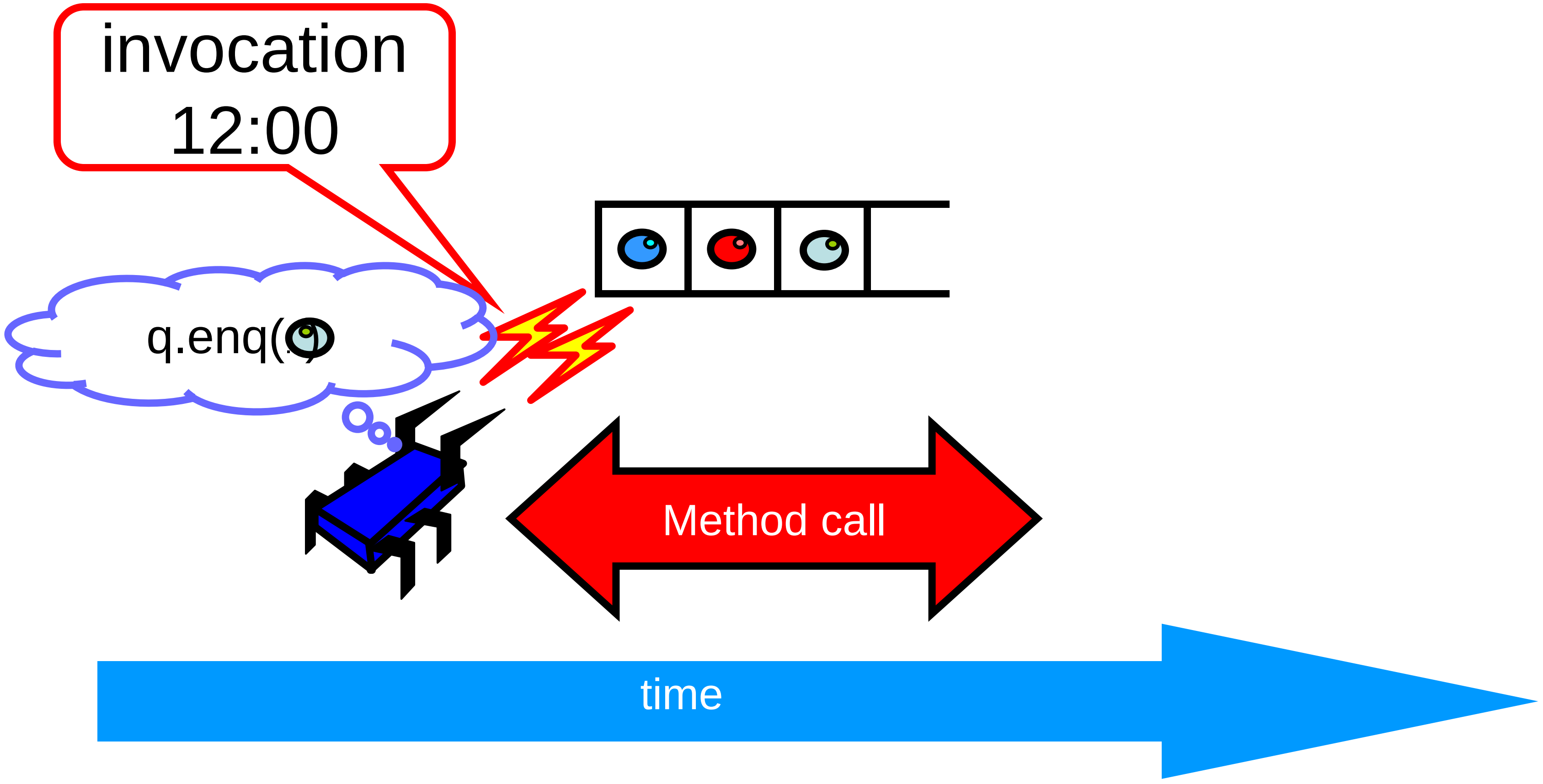

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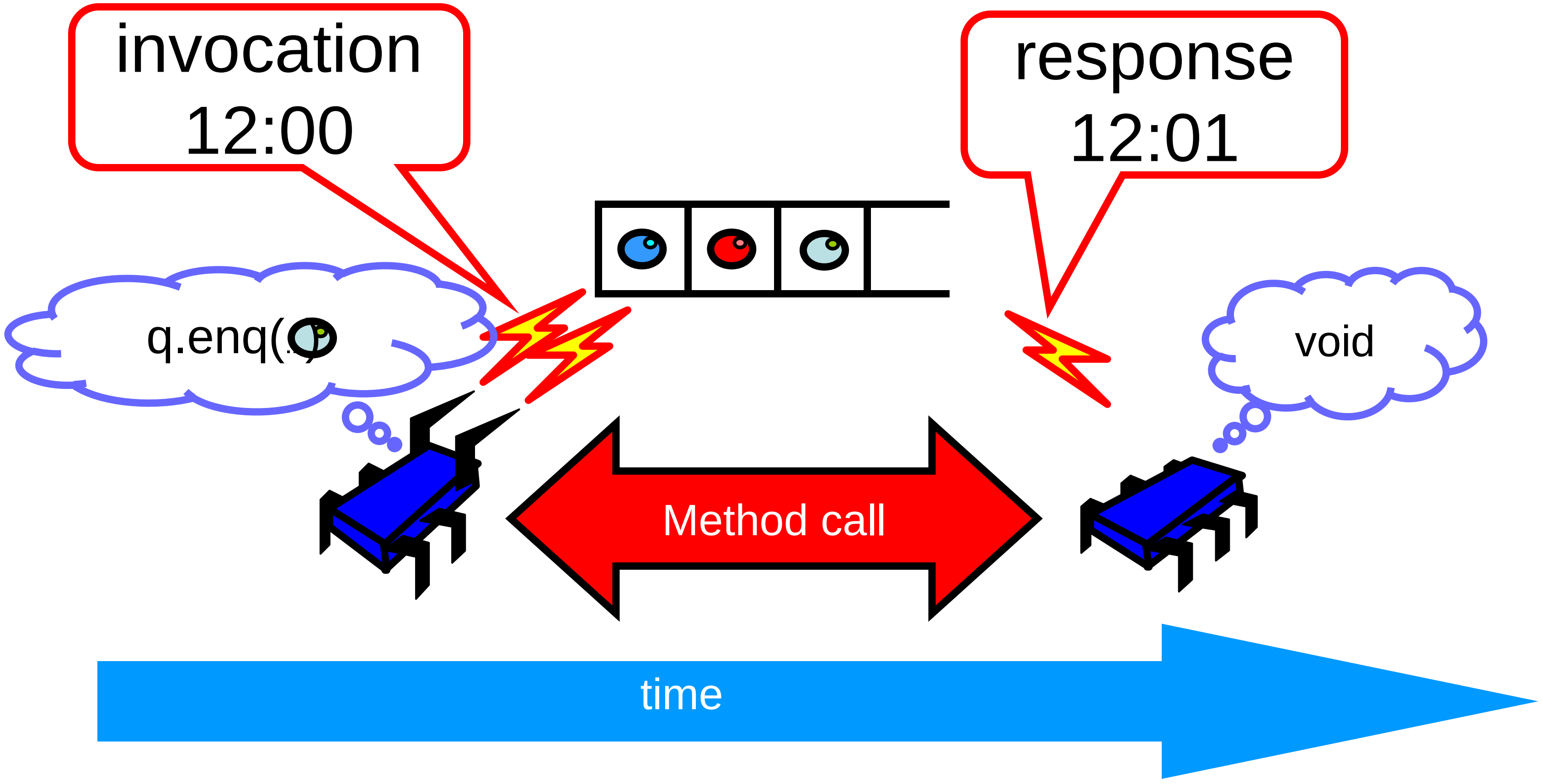
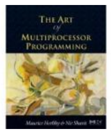
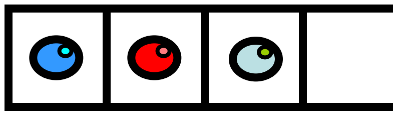
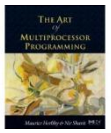




Concurrent Methods Take Overlapping Time





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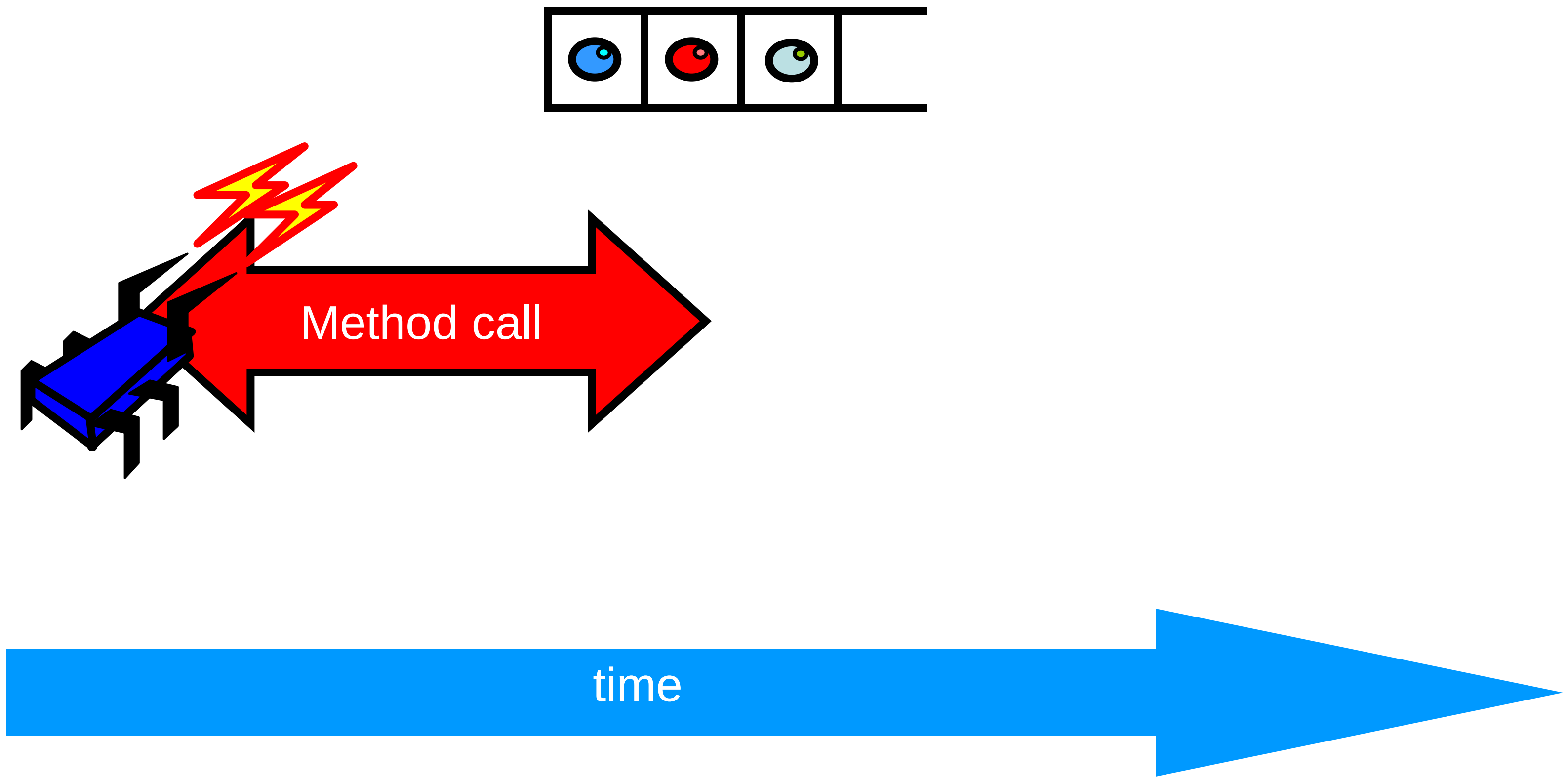

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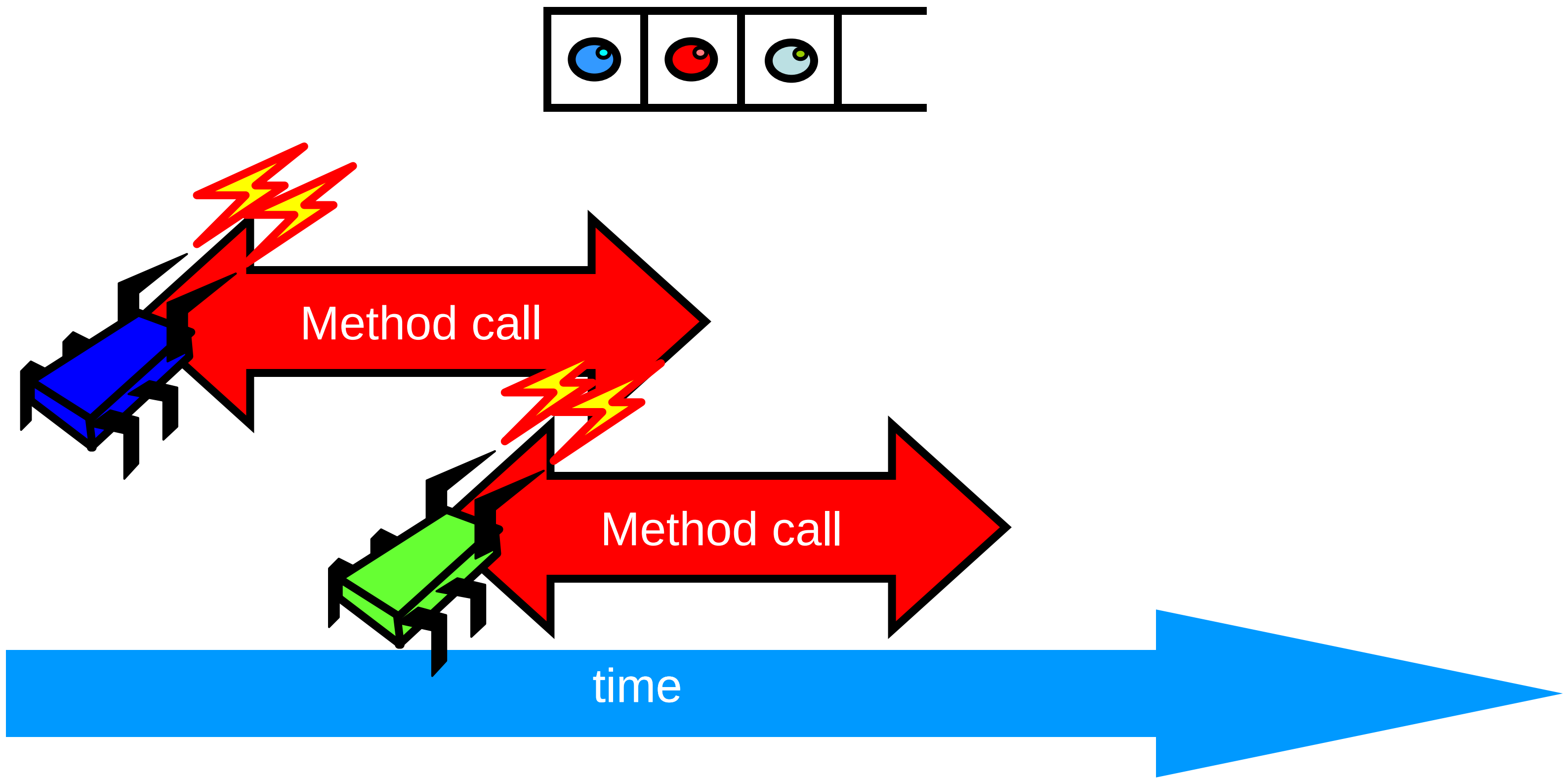

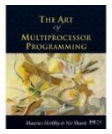

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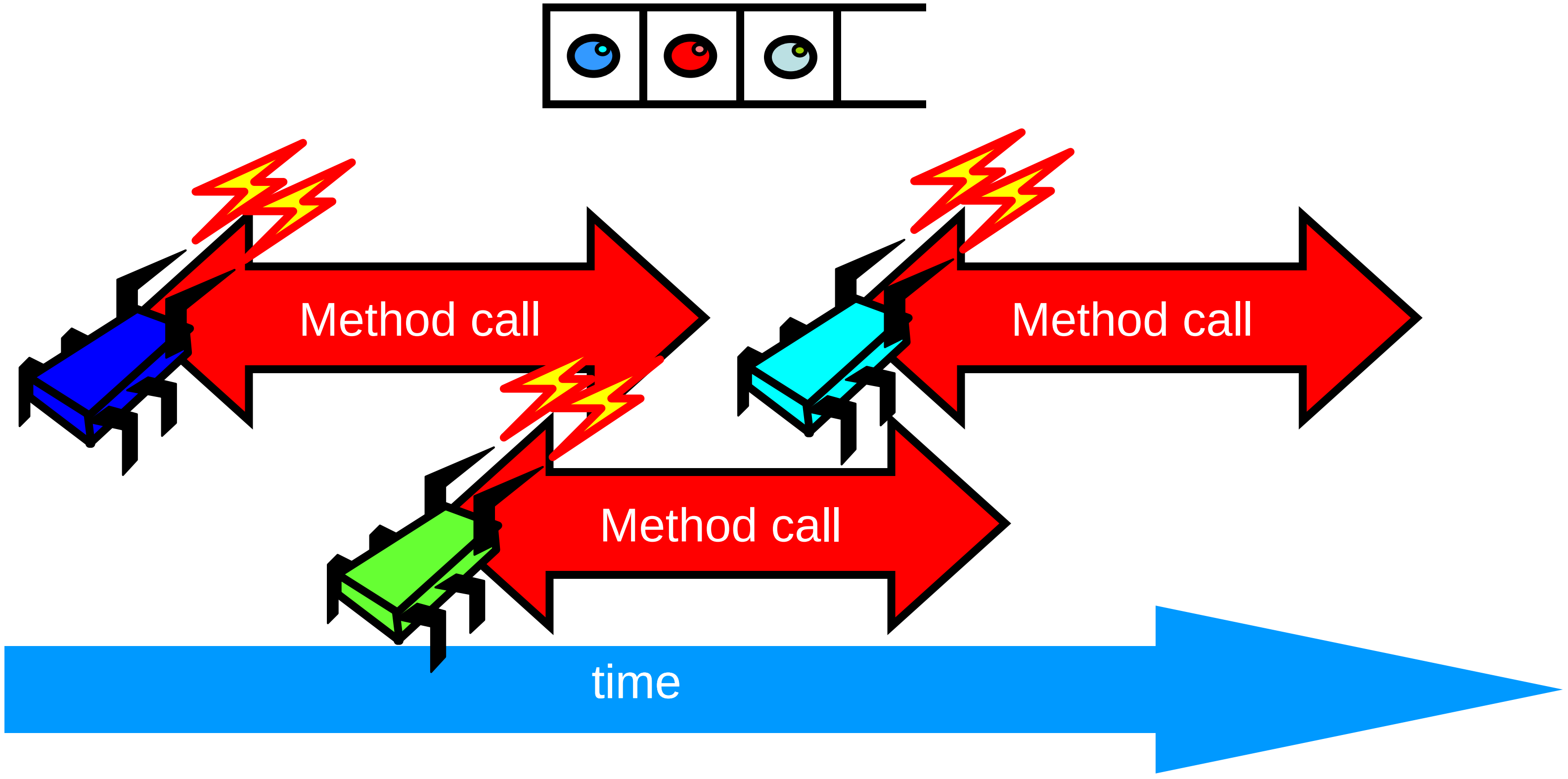
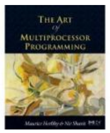
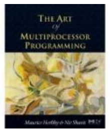


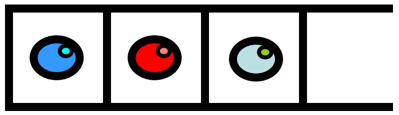


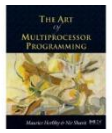
Linearizability

- Each method should
  - "take effect"
  - Instantaneously
  - Between invocation and response events
- Object is correct if this "sequential" behavior is correct
- Any such concurrent object is
  - **Linearizable™**



Example





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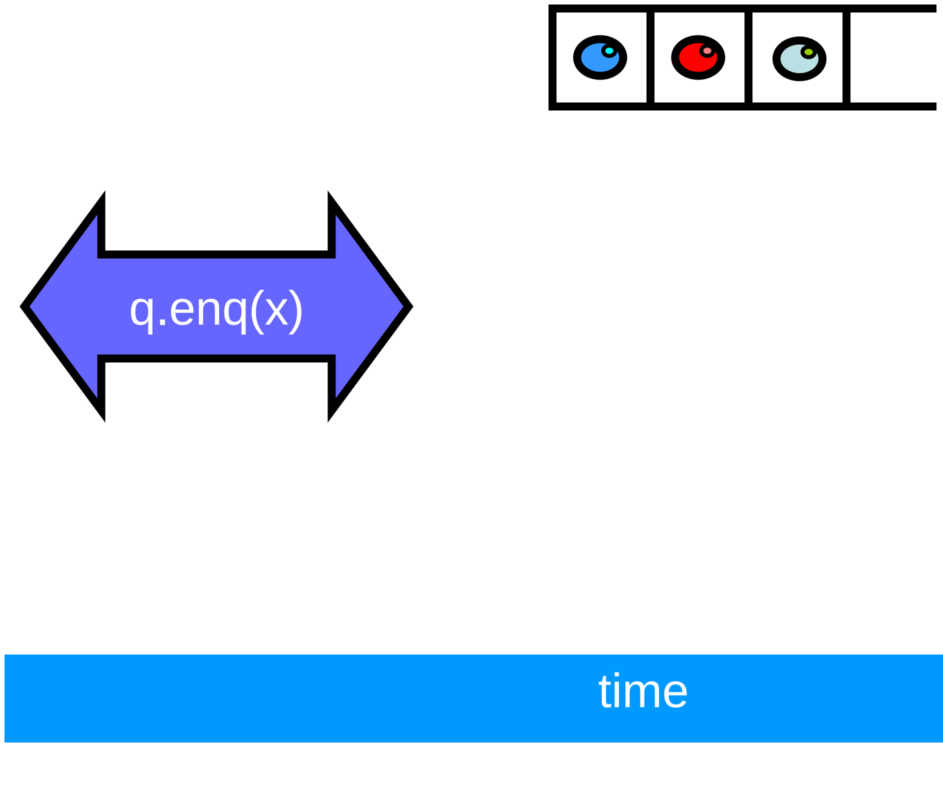

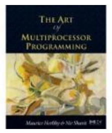

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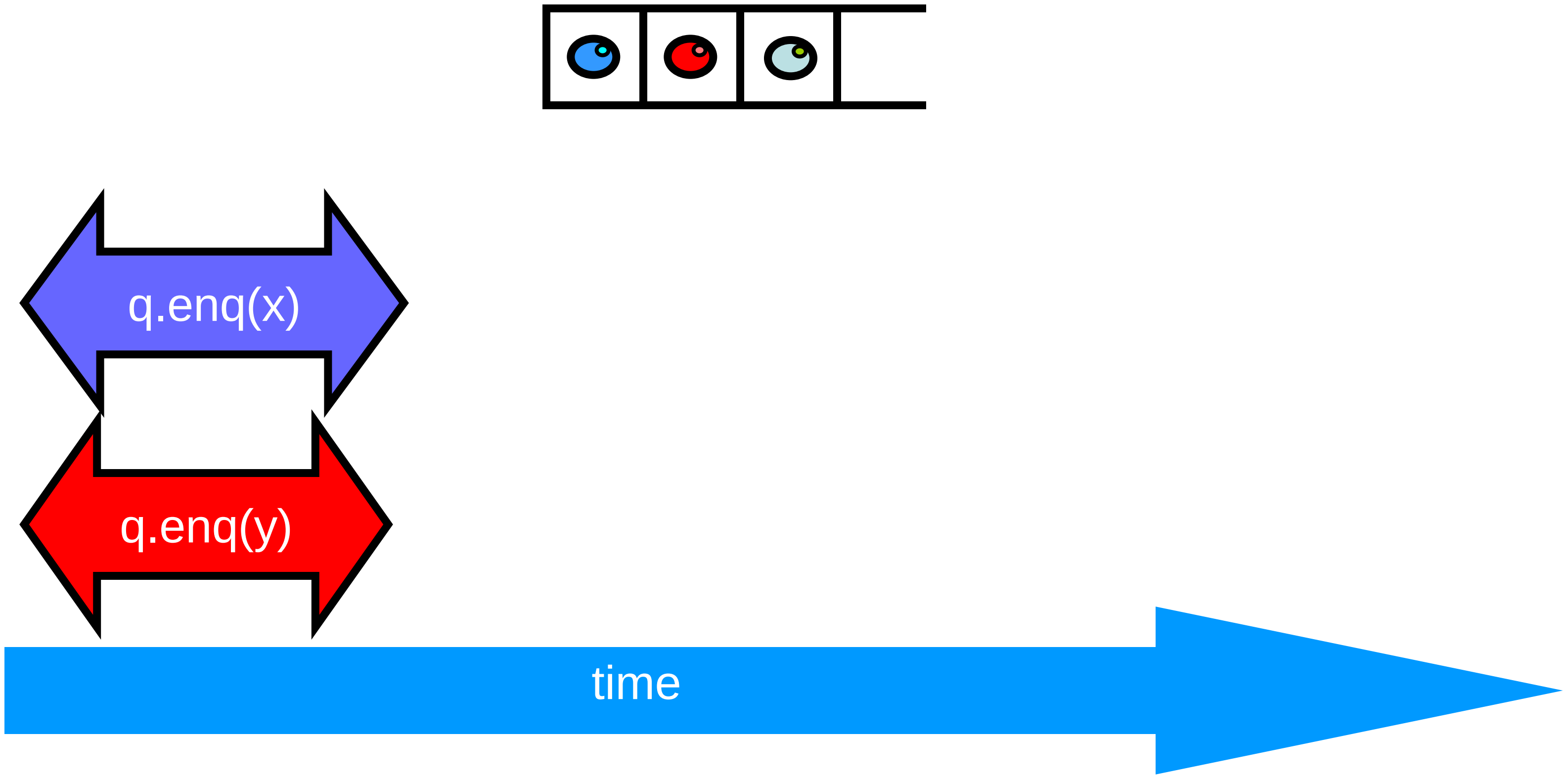

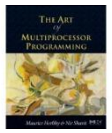

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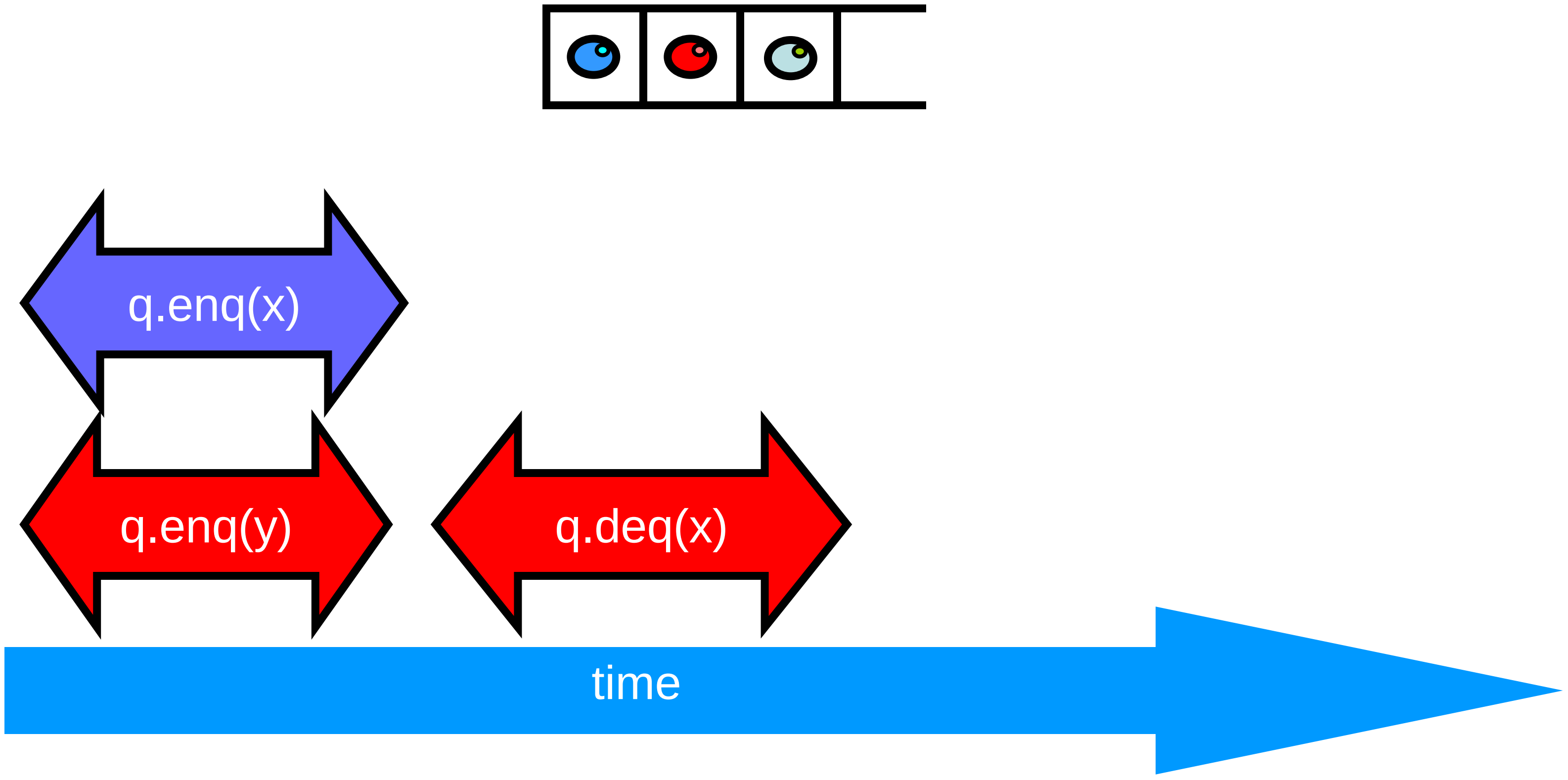

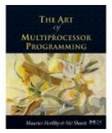

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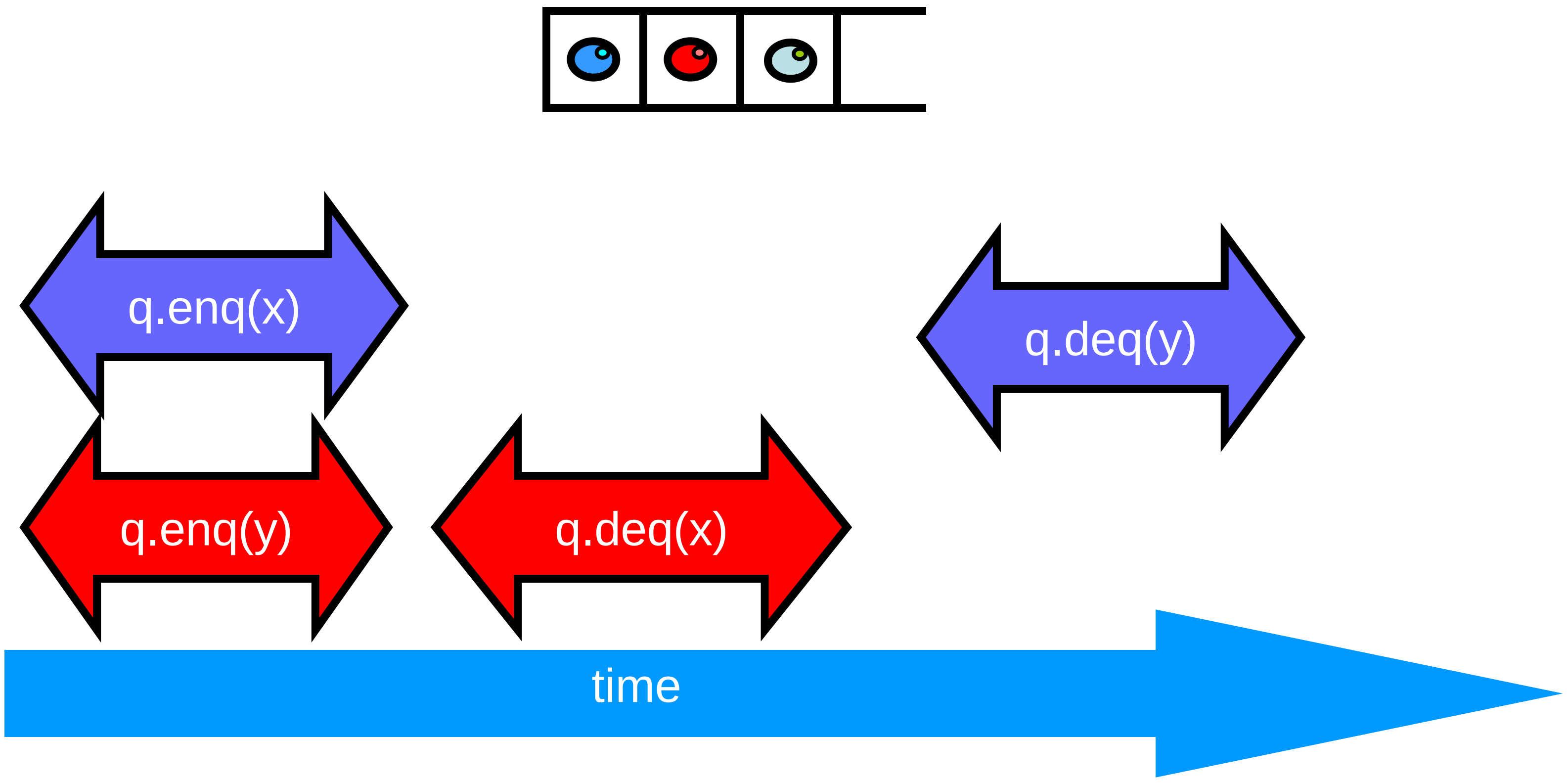

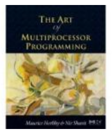

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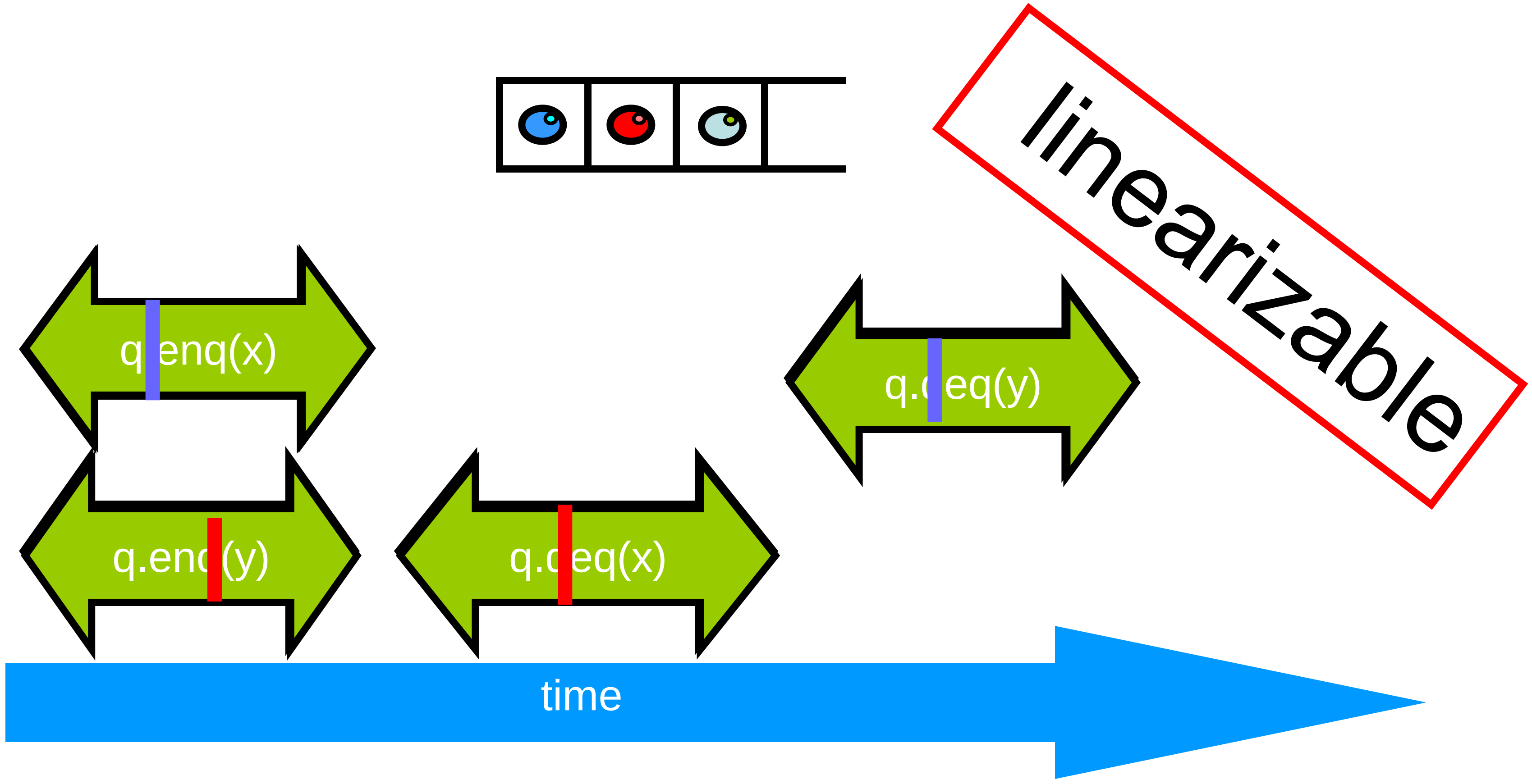
linearizable
q.enq(x)
q.deq(y)
q.enq(y)
q.deq(x)
time