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# Practical Parallel Processing

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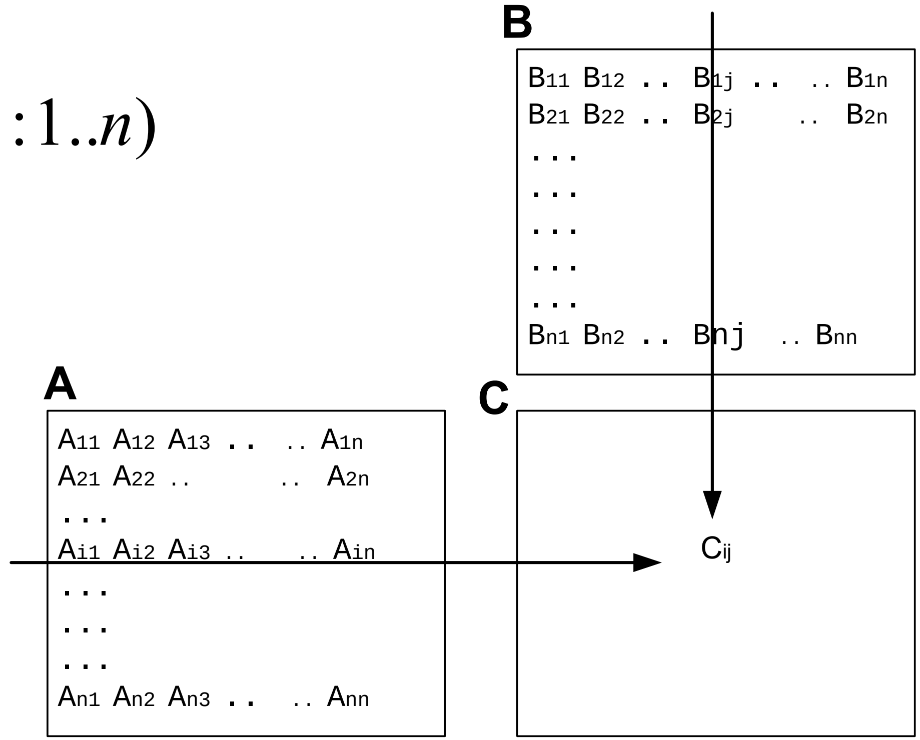
# Example: Matrix Multiplication

$$C = A \times B$$

$$C_{ij} = \sum_{k=1}^{n} A_{ik} . B_{kj} \quad (i, j : 1..n)$$

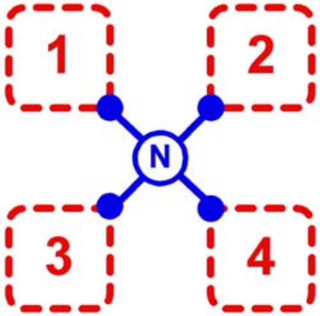
$$T_{computation} = \delta_{mm} . n^3$$




**Sequential algorithm**

# Parallel Matrix Multiplication

- Parallel System

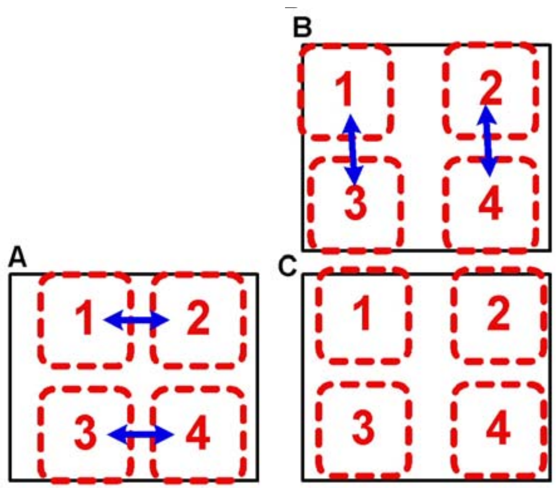



- Partitioning

p blocks of $n^2/p$ elements

- Submatrix $C_{i,j}$:

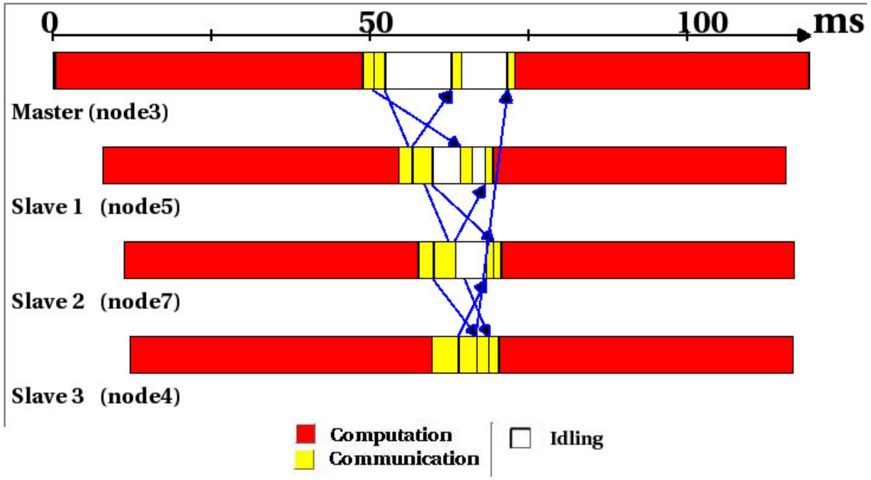
$$C_{i,j=}\sum_{k=1}^{\sqrt{p}} A_{i,rowk} . B_{colum\ k,j}$$



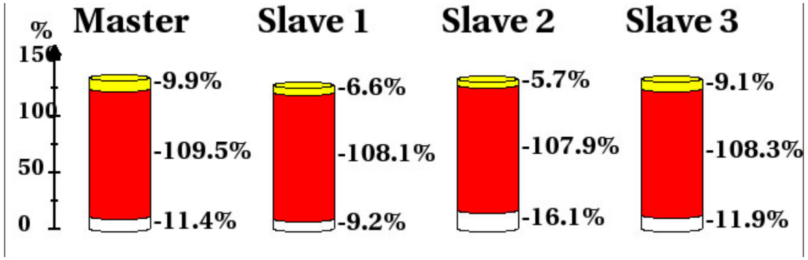

- Communication

# Parallel Matrix Multiplication

Execution profile
*n=150*

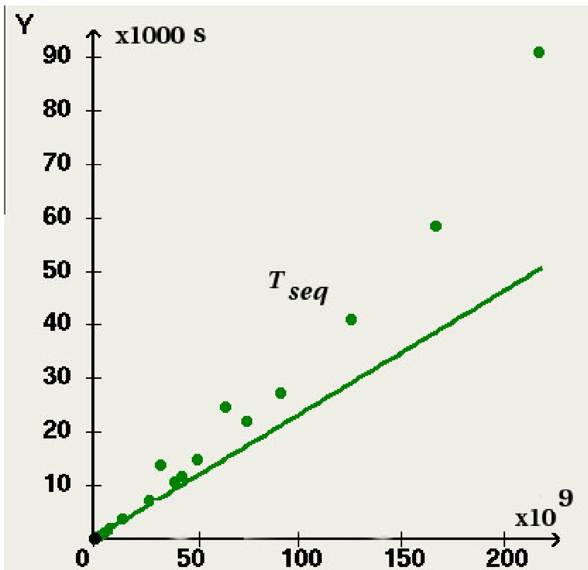


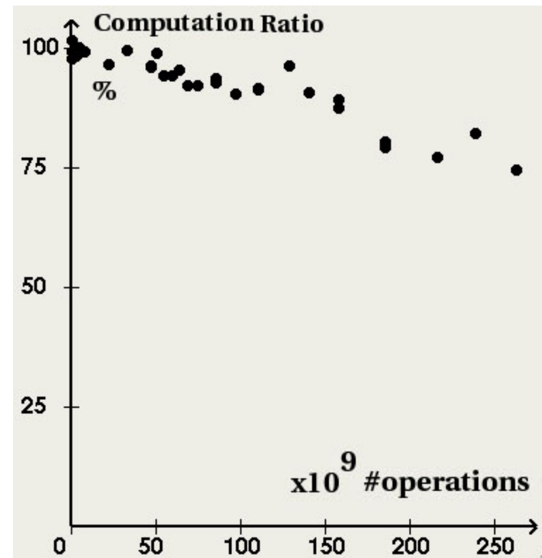

Extra work = overhead



# Parallel Matrix Multiplication

Memory usage ~ $n^2$

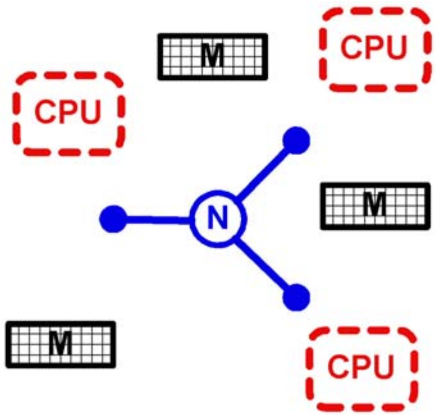


# Why Parallel Processing?

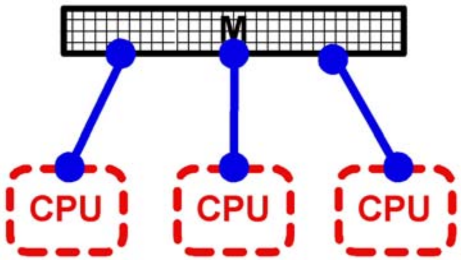
- Speedup (*time*)
  - for long runs
  - realtime (eg. Simulations)
  - as much as possible (eg. weather forecasting)
- Memory Usage (*space*)

# Parallel Systems



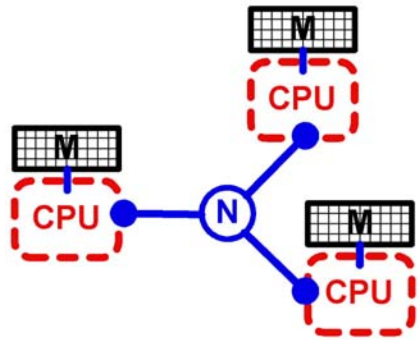

Collection of
- Processors
- Memory
- Interconnection Network

## 1. Shared-Memory Architecture




– fast communication
– dedicated machines

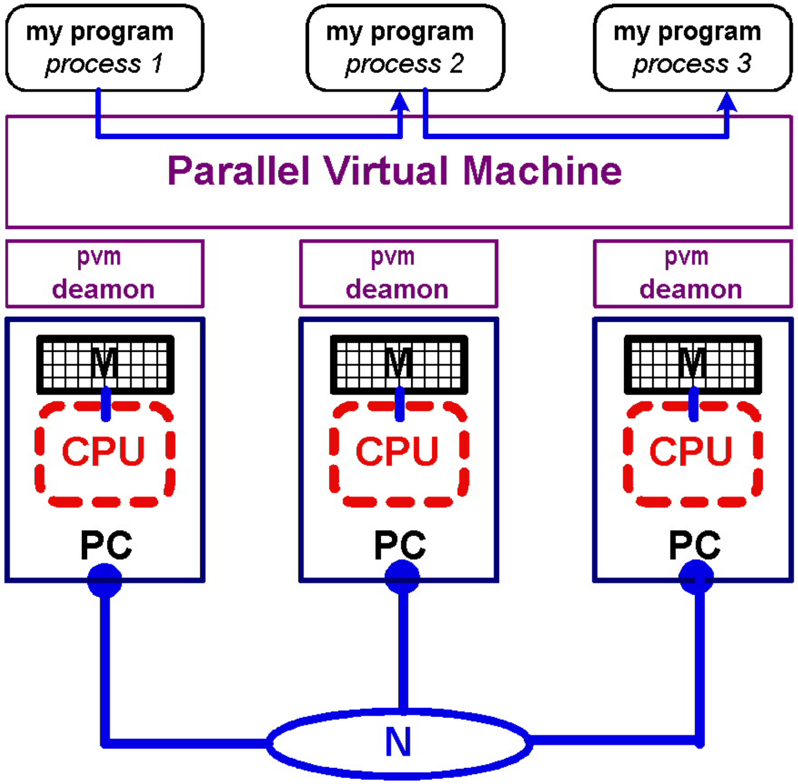
## 2. Message-Passing Architecture




- slower communicatio
- simple, cheap
general-purpose PC's

# How? Communication Layer

- ***Pvm*** (Parallel Virtual Machine) or ***MPI*** (Message Passing Interface)
  - transparant
  - platform-independent
- ***Functions***
  - create processes on other machines
  - send & receive messages



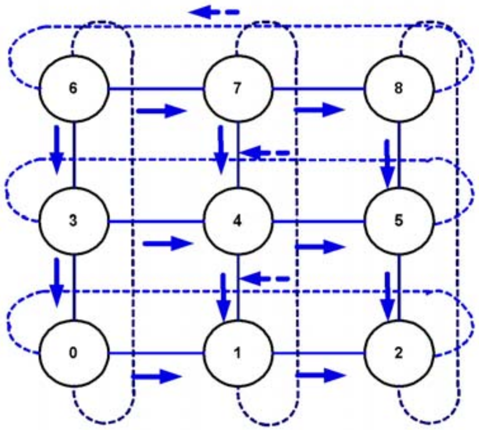
# Aspects of Practical Parallelization

1. System-dependency
2. Inherent Parallelism
3. Software Engineering
4. Performance Analysis

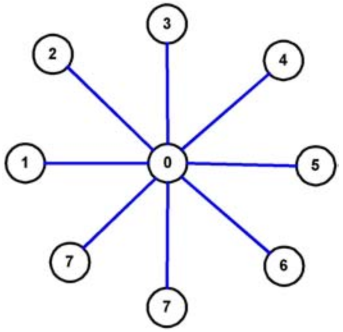
# 1. System-dependency

- Network Topology

Mesh network




Star network




- Heterogeneous Systems

  - different processing powers
  - different communication speeds
  - combinations of shared memory & message passing architectures

# 2. Inherent Parallelism

- ***Trivial parallelizable***
  - replicated trials (multiple experiments)
    - => script
  - multiple jobs
    - => job management

# 2. Inherent Parallelism II

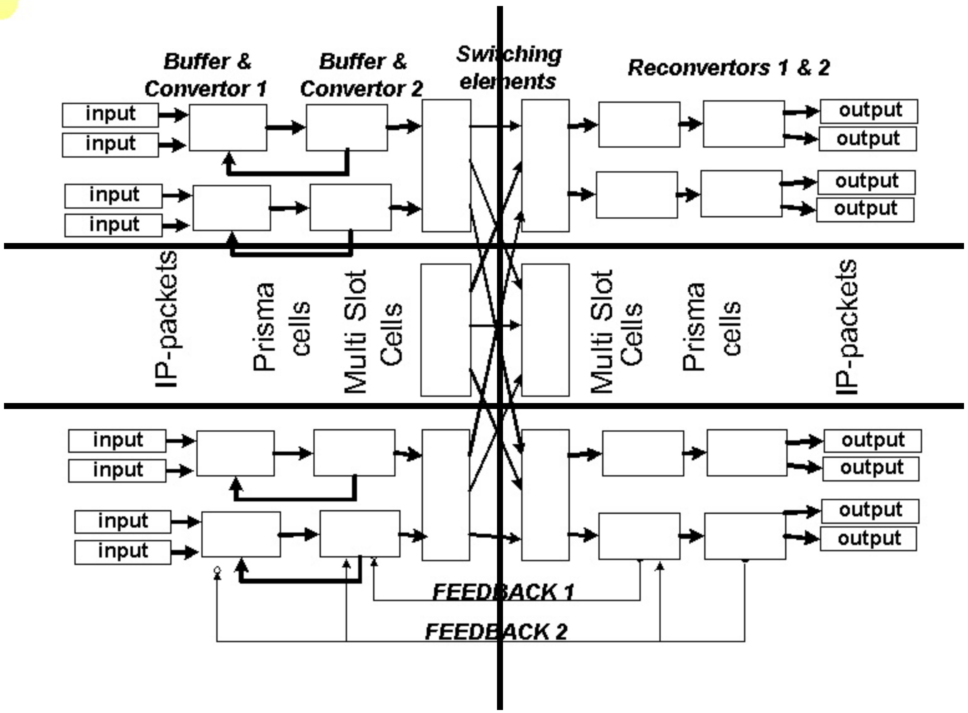
- ***Difficult to Parallelize***
  - Simulations
    - Synchronization protocol
    - Model dependent
  - Virtual 3D world
    - Tessalation, lighting calculations, rendering…

> Performance depends on various aspects, like data structures

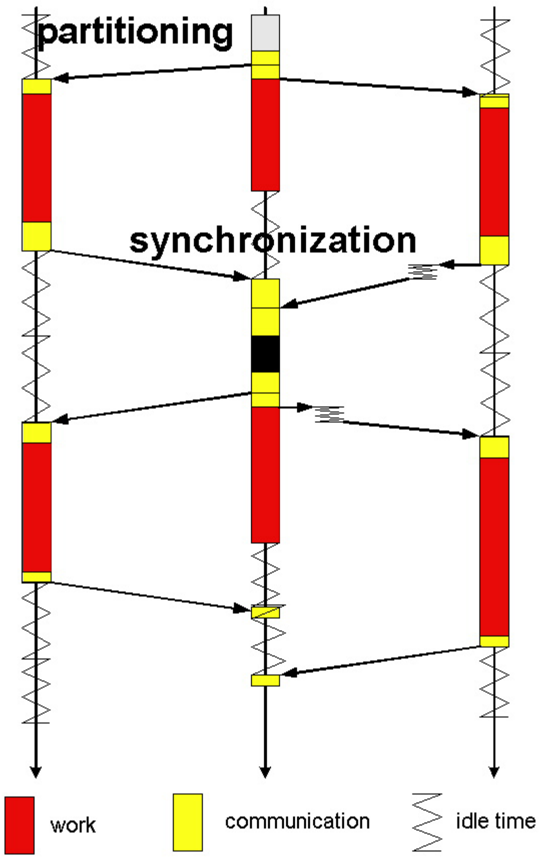
> Optimizations are possible, but strongly depend on problem/algorithm

# Example: Parallel Simulation

## Detailed IP-switch




## Execution profile



# 3. Software Engineering

- Understandable, Maintainable
  - tangled code!
- Flexible
  - separate parallel code
  - Eg.: reuse sequential algorithm, so it can be adapted
- Reusable
  - trade-off generic program <> performance

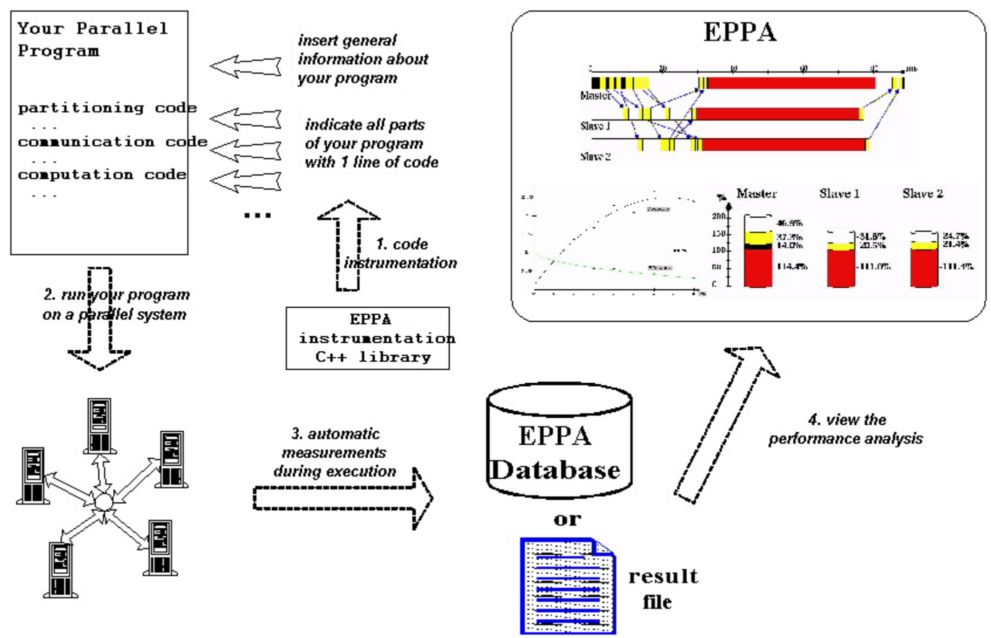
# 4. Performance Analysis

- Detection of performance bottlenecks
  - For example
    - communication-computation ratio
    - load imbalances
- Scalability analysis
  - bigger problem => more computers
- Calculation of optimal number of processors

# Performance Analysis Tools

- Automated analysis
  - Simple: XPvm
  - Complex
- However: Userfriendliness

=> EPPA

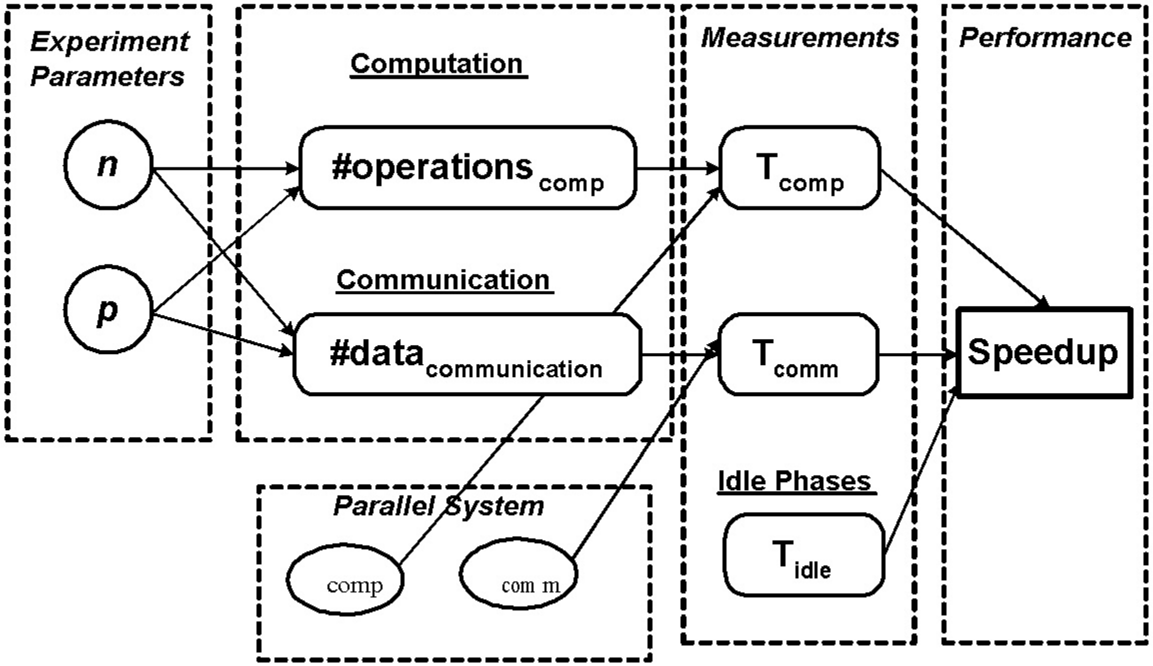


# Our Performance Analysis Tool

Parallel Systems lab

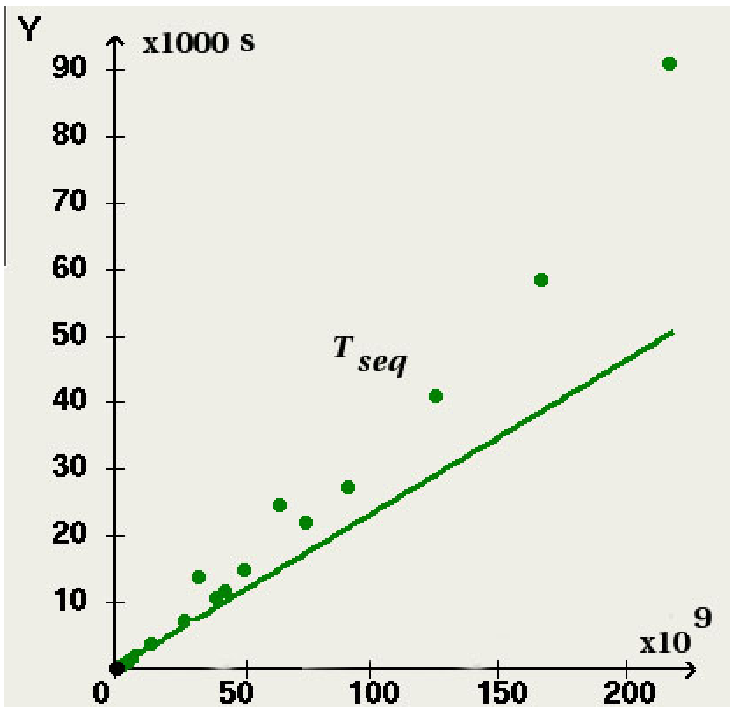
## 1. Causal Models

to structure the relations between the variables



# Our Performance Analysis Tool II

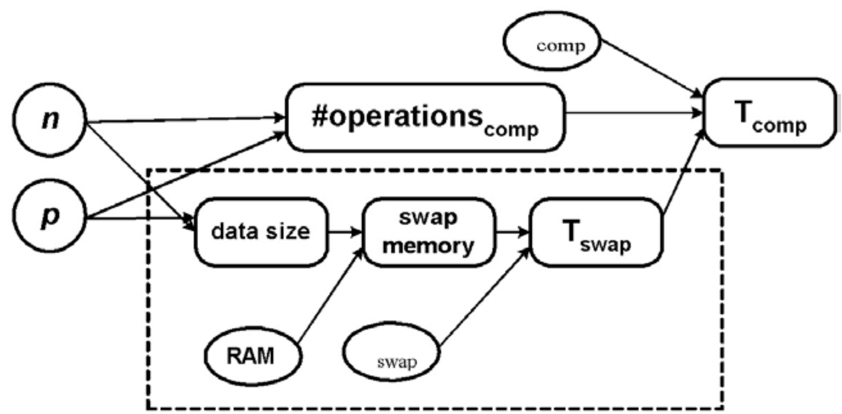
## 2. Refinement Strategy




Start: First-order approximation

$$T_{computation} = \partial_{comp} .\# operations.$$

Refine when necessary



# Theoretical Conclusions

## Sequential world

- Separation hardware – program (3GL)
  With abstract model for architecture: Von Neuman
- Java: platform-independence
- .net: language-independence

## Parallel world

Ultimate goal: match software - hardware

*No universal abstract model for parallel architectures!*

Conflict generality <> efficiency

Performance is program- and hardware dependent

Efficient programs should be developed specifically …

# Practical Conclusions

- Successful parallel processing is a complex issue
  - But not ….
- Thus:
  - Is it worth it?
  - Is it possible?
  - Is it easy?
- Effort ~ Benefit