Distributed BEAGLE:
An Environment for Parallel and Distributed Evolutionary Computations

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Outline

- Evolutionary Computations (EC)
- Parallel and Distributed EC
- Master-slave architecture
- Deployment scenario
- Proposed implementation

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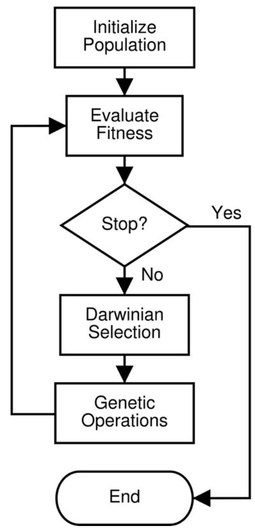
Evolutionary Computations (EC)

- Simulation of natural evolution on computers
- Generic problem-solving method
  - Solutions represented by data structures
  - Objective function (fitness)
- Population of solutions that evolve over time
- Optimization, machine learning, automatic design



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Four Flavors of EC

- Genetic Algorithms (Holland, 1975)
  - Vectors of characters: <10011000111>
  - **Crossover**, mutation, selection
- Genetic Programming (Koza, 1992)
  - Solutions = LISP *s*-expressions (programs)
- Evolution Strategy (Rechenberg, 1973)
  - Vectors of floating-point numbers
  - Mutation strategy
- Evolutionary Programming (Fogel et al., 1966)
  - At first finite state machines, later vectors of floats
  - Mutation specific to the representation

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Implementing EC

Data structures

- Population of solutions
  - Bit strings (GA)
  - Graph representing programs (GP)
- Containers and dynamic polymorphism

Algorithms

- Evolutionary loop with operators
  - Fitness evaluation
  - Genetic operations
- *Strategy* design pattern

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Parallel and Distributed EC = PDEC

- EC need huge CPU resources
- EC are implicitly parallel: a population of independent solutions evolving in parallel
- For real world problems, solution fitness evaluation is the computation bottleneck
- PDEC is a hot topic: Beowulf clusters are cheap and well adapted for PDEC

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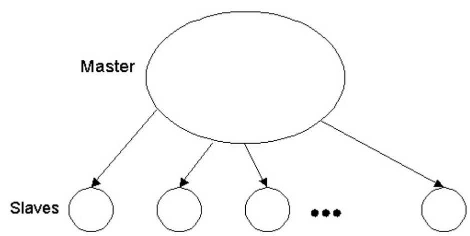
Master-Slave



- Master stores the whole population and applies genetic operators
- Master distributes individuals to the slaves for fitness evaluation

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Pros and Cons of Master-Slave

- Pros
  - Simple transposition of sequential model
  - Node can be added/removed dynamically
  - Robust to slave failures
  - Simplifies data collection/analysis
- Cons
  - If the master crashes the whole system goes down
  - Communication overhead
  - May not scale well when the master is overloaded
  - Synchronization overhead for lagging slaves

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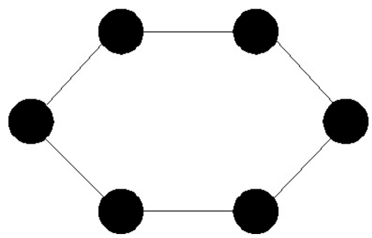
Island-Model



- Isolated evolutions with a migration process
- Encourages diversity and prevents premature convergence
- 1 CPU = 1 population

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Pros and Cons of Island-Model

- Pros
  - Scales very well
  - Low communication overhead
  - Robust to failures (willing to lose small populations)
  - Higher diversity: isolated populations with migration
- Cons
  - Load balancing on heterogeneous networks
  - Dynamic reconfiguration of network
  - Evolution cannot be reproduced
  - Difficult data collection/analysis

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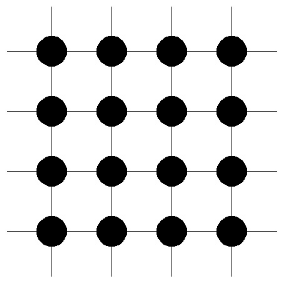
Fine Grained & Hierarchical Hybrid

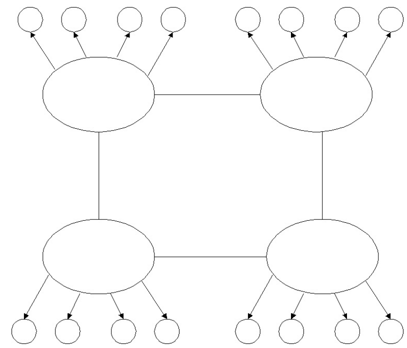
Fine Grained

- Populations spatially distributed on processors
- One individual per processor (SIMD)



Hierarchical Hybrid

- Hybrid of master-slave and island-model



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Designing a PDEC System

- Networks of computers
  - Beowulf clusters
  - LAN of heterogeneous workstations used during idle time (screen-saver)
- Processing nodes dynamically added/removed
  - Hard failures: system crash/reboot, network problem
  - Soft failures: user deactivates the screen-saver

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Options

- Master-slave
  - Communication bottleneck
  - Robust to failures: task of a slave can be easily redispatched
- Island-model
  - Scales very well, peer-to-peer, WAN
  - Independent populations (1 proc. = 1 pop.)
  - MTBF << evolution time?

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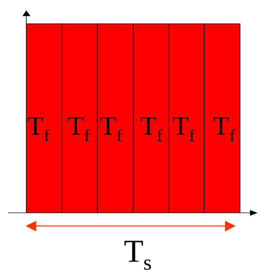
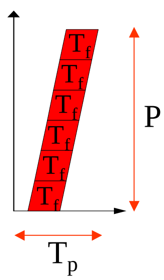
Speedup of Master-Slave

$$speedup = \frac{T_s}{T_p} \qquad T_s = NT_f$$





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Parameters

- N: population size
- P: number of processors (slaves)
- T_f: average fitness evaluation time
- T_c: average communication time
- T_l: average connection latency
- S: average number of solutions composing a distribution set
- C: number of evaluation cycle
- K: number of failures observed during a generation

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Distribution Policies

- S = number of solutions sent to each slave during each communication cycle
- Two common policies:
  - P processors, P sets of size N / P (S = N / P)
  - one-by-one (S = 1)
- Third option: adaptive S

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Assumptions

- Computers with similar performance (variance of S is small)
- Averaged time values
- Constant number of processors

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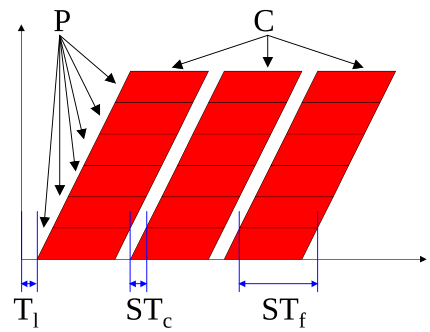
Illustrating Values

- S: size of sets
- P: # of processors
- C: # of evaluation cycles
- T_f: fitness time
- T_c: transmission time
- T_l: latency time



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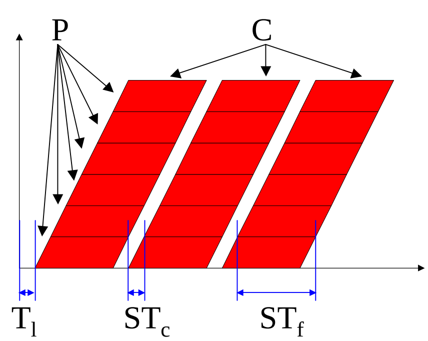
Mathematical Modelization

$$T_p = \underbrace{CST_f}_{\text{computation}} + \underbrace{CPST_c}_{\text{communication}} + \underbrace{CT_l}_{\text{latency}} + \underbrace{T_k}_{\text{failures}}$$



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Failure Delay

$$T_k = \begin{cases} 0 & K = 0 \\ \underbrace{(1-0.5^K)ST_f}_{\text{synchronization}} + \underbrace{KST_c}_{\text{comm.}} + \underbrace{T_l}_{\text{latency}} & K \in [1, P] \end{cases}$$

- K: the number of observed failures
- Synchronization term: under the assumption that failures are independent, follow a Poisson process, and happen half-way through the fitness evaluation process

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Plausible Scenario: Beowulf

- 100 Base-T switches (7MBps effective bandwidth)
- Average fitness evaluation time T_f = 1 s
- Solution = 1KByte -> T_c = 0.14 ms
- Average connection latency T_l = 0.1 s
- 500 000 solutions
- Between 1 and 400 processors
- Size of sets S = {1, 10, 0.1N/P, N/P}

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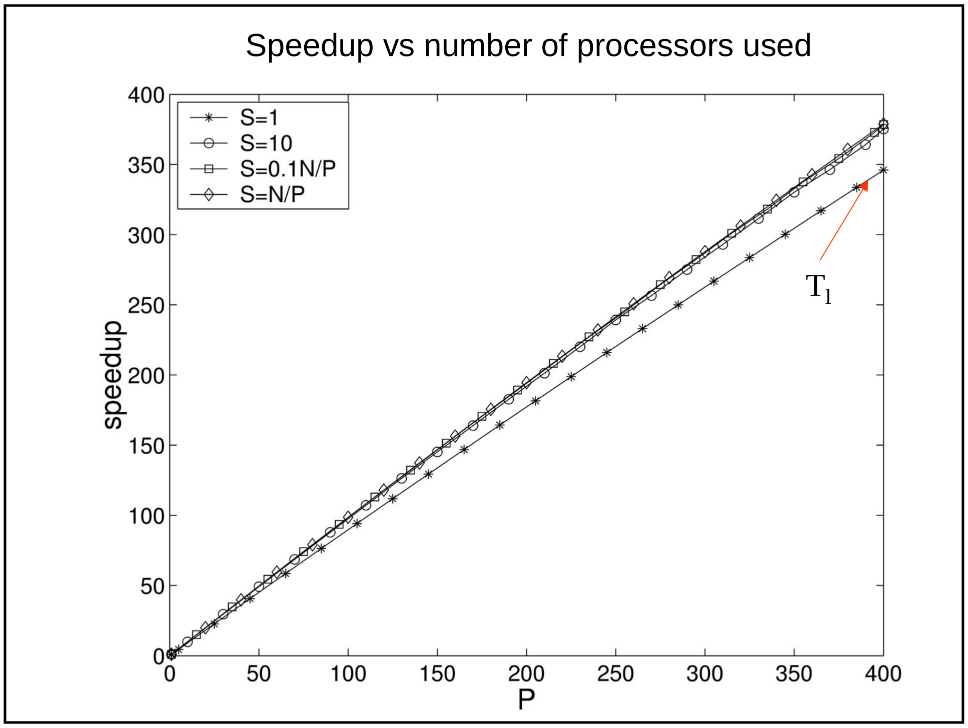
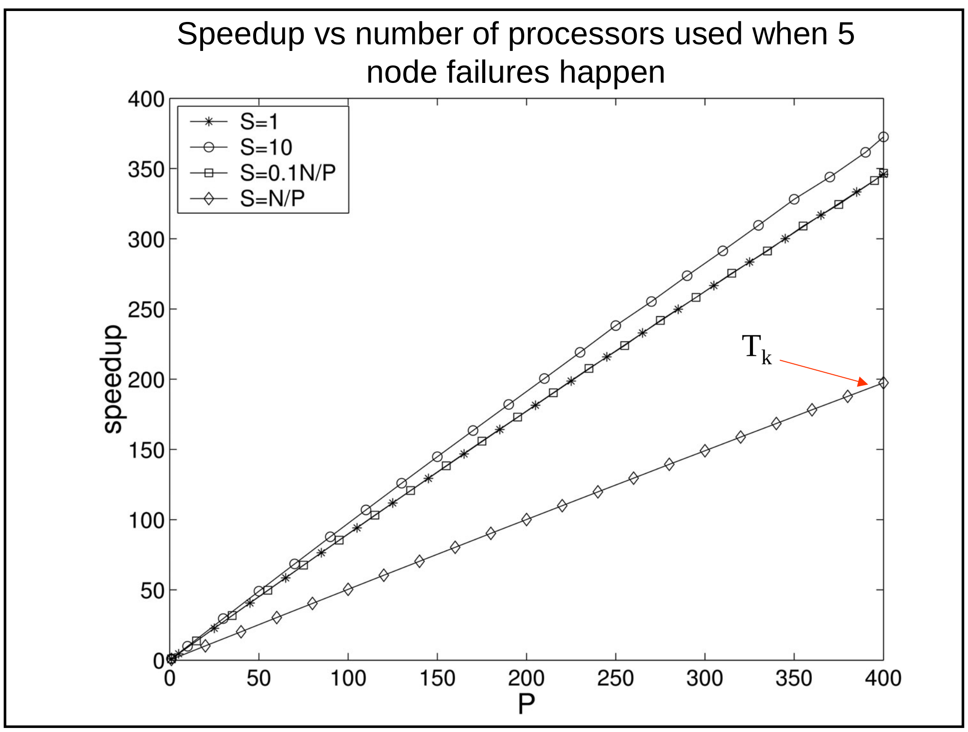
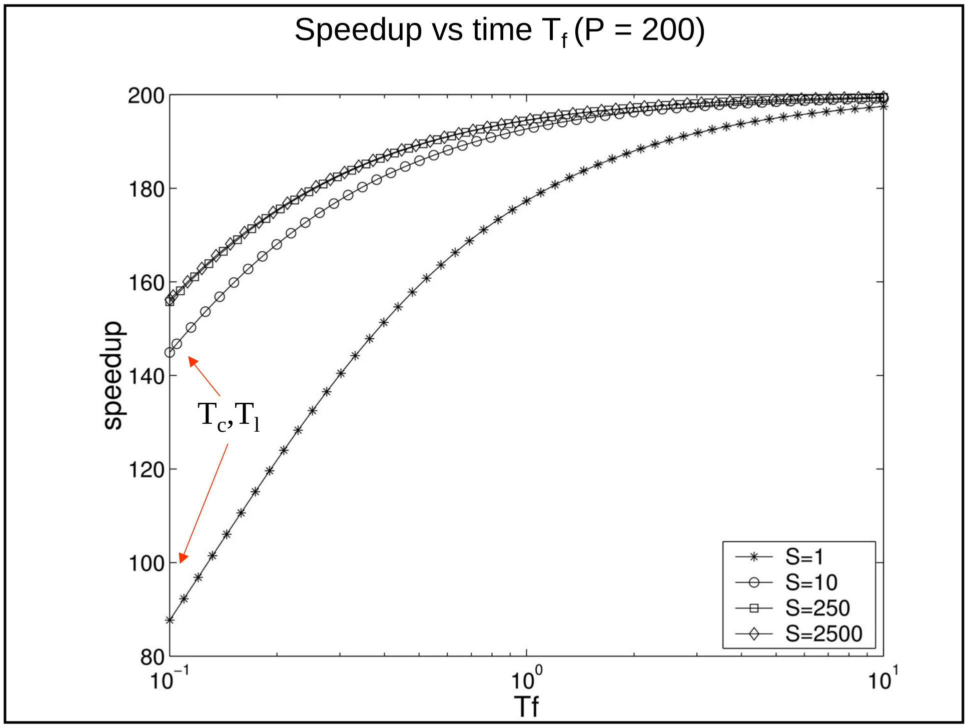
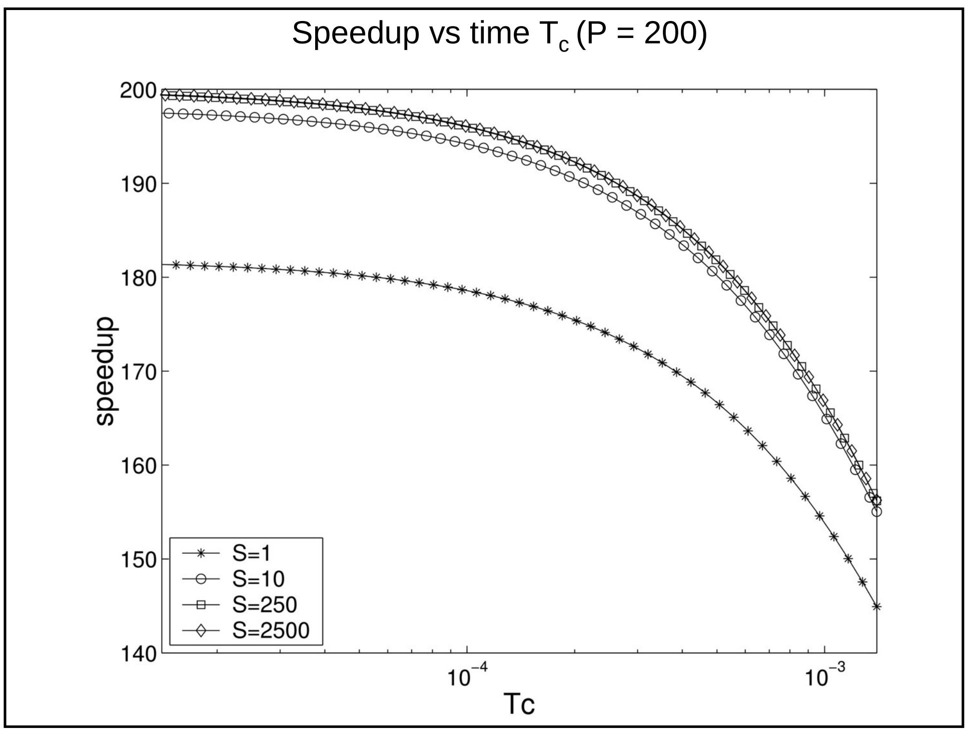
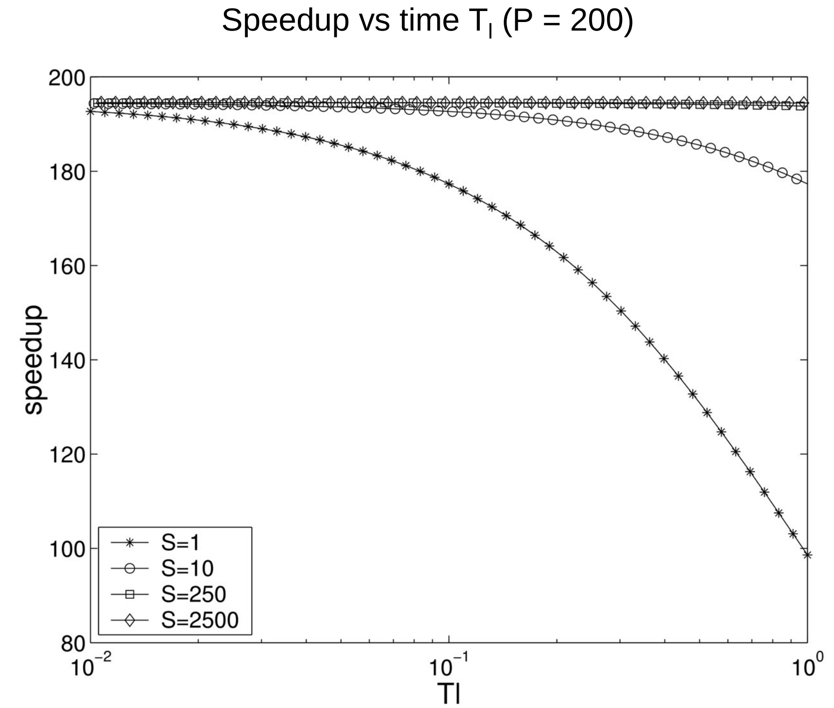

Speedup vs number of processors used
speedup
P
S=1
S=10
S=0.1N/P
S=N/P
T_l


Speedup vs number of processors used when 5 node failures happen
speedup
P
S=1
S=10
S=0.1N/P
S=N/P
T_k


Speedup vs time T_f (P = 200)
speedup
Tf
T_c, T_l
S=1
S=10
S=250
S=2500
200
180
160
140
120
100
80
10^-1
10^0
10^1


Speedup vs time T_c (P = 200)
speedup
Tc
S=1
S=10
S=250
S=2500
200
190
180
170
160
150
140
10^-4
10^-3



Communication Bottleneck

- In this scenario, master-slave scales to more than 7000 processors before network saturation (speedup around 3500)
- Use of intermediary size sets S necessary to achieve best performances (trade-off between latency and failures penalty)

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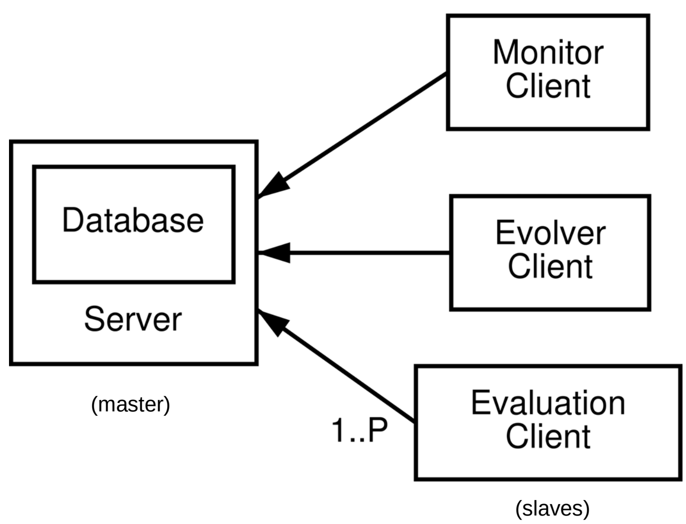
Distributed BEAGLE



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Characteristics

- Dynamic adjustment of the size of sets S based on previous results
- Redistribution of data when slaves are lagging
- Support for multiple populations: island-model with synchronous migration can be simulated to promote diversity
- Independent of the EC system and algorithm used

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Technologies

- Coded in C++
- SQL database for data persistency
- Communication based on TCP sockets
- Messages exchanged between the clients and the server encoded in XML

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State of Developments

- There is already a working prototype
- Public release as open source project
- Integrated with the C++ EC framework Open BEAGLE (http://www.gel.ulaval.ca/~beagle)

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Conclusion

- Master-slave is usable for LAN of workstations with limited availability
- Master-slave scales well (up to a certain point)
- Size of set S should be dynamically adjusted
- Distributed BEAGLE: a master-slave architecture for networks of computers with limited availability

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