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
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

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
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

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
Master-Slave

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

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
Island-Model

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

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
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

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
Options

- Master-slave
  - Communication bottleneck
  - Robust to failures: task of a slave can be easily redispached
- 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

\[
speedup = \frac{T_s}{T_p} \quad T_s = NT_f
\]

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
**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 $S$

**Assumptions**

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

Mathematical Modelization

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

\[ T_k = \begin{cases} 
(1 - 0.5^K)ST_f & \text{for } K = 0 \\
KST_c + T_l & \text{for } K \in [1, P] 
\end{cases} \]

- \(K\): 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

**Plausible Scenario: Beowulf**

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

- $S=1$
- $S=10$
- $S=0.1N/P$
- $S=N/P$

Speedup vs number of processors used when 5 node failures happen

- $S=1$
- $S=10$
- $S=0.1N/P$
- $S=N/P$
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

- Database
- Server (master)
- Monitor Client
- Evolver Client
- Evaluation Client (slaves)
- 1..P
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

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
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)

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