Scaling the Geneva library collection to large HPC clusters

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Who we are

• Gemfony scientific
  – A spinoff from Steinbuch Centre for Computing at Karlsruhe Institute of Technology

• With particular experience in the fields of
  – Optimization of complex systems
  – Technical- and Science-Consulting
  – Implementation of IT-Solutions
  – Technical Marketing, PR and Training

• Long standing background in parametric optimization
  – Gemfony maintains the Geneva library collection of distributed optimization algorithms
Parametric Optimization: Finding maxima or minina of $\bar{Q} = \bar{f}(x_1, x_2, ..., x_n)$

- Any mapping "$f$" from input parameters to one or more numeric evaluations can be optimized
- For one evaluation criterion: optimization == finding suitable minima or maxima of solver "$f$"
  - Very similar to the search for extreme values of mathematical functions
  - "Solution space" for multiple criteria
- However in the general case, "$f$" will be a computer program
- Hence standard mathematical procedures cannot be applied easily
- Solvers may be computationally expensive
- As optimization algorithms will typically call the solver hundreds or thousands of times, such optimization problems will greatly benefit from parallelization
Parallelizability on the Example of Evolutionary Algorithms

Rastrigin / iteration 0 / fitness = 76.7586

Initial Population

Best Individual

Optimum

Rastrigin / iteration 1 / fitness = 19.7801

Best Individual

Optimum

Rastrigin / iteration 2 / fitness = 10.0394

Rastrigin / iteration 3 / fitness = 4.56426

Surface plot of the Rastrigin function

"Gauss-Mutation"

Gmfony scientific
• Why in „Massively Distributed Computing and Citizen Sciences“

• While this is probably not an exact fit:
  – Geneva is commercially supported Open Source (see http://www.launchpad.net/geneva)
  – Geneva particularly targets distributed and parallel execution
  – As optimization is a generic topic, application scenarios target just about every aspect of daily life
  – Free (simulation-) tools, along with cheap cloud resources, allow research to be performed by all scientifically interested parties
The Geneva Library Collection

- Generic solution for the search for **optimized solutions** of technical and scientific problems
- „Metaheuristic“ Optimization
  - Covering *Evolutionary Algorithms*, Swarm Algorithms, Simulated Annealing, Parameter Scans and Gradient Descents
- Data structures allow direct interaction between different optimization algorithms with **just one problem description**
- Written in portable C++
  - Uses the Boost library collection
  - Runs on different Unix variants (Linux, MacOS, ...) and Windows (experimental!)
- > 130,000 LOC (.hpp, .cpp, scripts, ...)

Sources:
- Car: Image courtesy of Simon Howden at FreeDigitalPhotos.net
- Wind turbines: [http://www.flickr.com/photos/pebondestad/3533177131/sizes/l/in/photostream/] (Creative Commons Attribution 2.0; By Pål Espen Bondestad)
- Particle decay: [https://en.wikipedia.org/wiki/File:CMS_Higgs-event.jpg] (Creative Commons Attribution Share-Alike 3.0; By CERN)
Library Components

Strong modularization allows for an efficient decoupling of evaluation and optimization!
Tuning Scalability

- „Performance“ is very problem-dependent
- In a nutshell, on the same hardware, performance improvements may be achieved in numerous ways, e.g.
  - Making the Geneva code more efficient
    - BUT: Focus on long-running evaluation-functions mandates focus on core-library stability rather than performance
    - Reducing run-time of the solver(s). But: task for the user
  - Making optimization algorithms converge faster
    - Minimization of Iterations needed to reach a given optimum
- But in particular: Parallelization of parallelizable parts
  - Reducing parallelization-overhead: „Amdahl“ may have a major impact on performance → Asynchronous transfer of candidate solutions
  - May need to cater for potentially thousands of clients, running for hours or days
- Reducing protocol overhead and improving stability is crucial
The „Courtier“ Library: Problem-Independent Parallelization

This will generally be an optimization algorithm.
Proactor Pattern

- **Boost.ASIO**
  - Uses operating system parallelization
    - Thus very efficient
  - Will likely be part of the next standard C++17
  - Main usage: tcp networking in C++
    - Need to deal with TCP oddities on the lowest level

Picture source: Wikipedia „Proactor“, License CC-BY-SA 3.0, Author UlrichAAB
Dissecting the Network Mode (1)

- Current usage pattern in the release version (pull-mode!)
  - Client connects, retrieves work item, disconnects, does calculation, reconnects, transfers a result and retrieves the next work item
  - Many sockets are opened and closed
  - If calculation time and speed of clients is similar, connections may happen within a very small time window → long idle times for the server, followed by short periods of very high traffic
  - From the server-perspective, the problem may be quite similar to a high-load web-server
- Chosen, as, from the library perspective, there is no information about the length of an evaluation -- may take seconds or days
  - Server must cater for missing responses
  - Timeout must be calculated and possibly clients resubmitted, which may be problematic
- Scales to approx. 100 clients, but shows many problems beyond this
Simultaneously open files per process:
  - E.g. on MacOS: „ulimit –n“ returns 256. Even on a stock Ubuntu: only set to 1000
  - But every new socket requires a file handle ...
  - ... and even when a socket is closed, the handle is kept around, possibly for minutes, depending on the TCP/IP implementation

Supply of “short-lived“ ports
  - By default 32768 – 61000 (range may be slightly increased)
  - Every new connection consumes a new port
    - E.g. two ssh connections to a server yields

```
# lsof | grep ssh | grep myName | awk '{print $2 }' | uniq
13316
23526
```
  - Unused ports are recycled ... after some time

Follows http://www.lognormal.com/blog/2012/09/27/linux-tcip-tuning/
Dissecting the Network Mode (3) / How to tune a frequent-access Linux server?

- **TIME_WAIT**
  - Purpose: Packages returning after a connection is closed do not confuse TCP
  - May last long ... 2 minutes not uncommon
  - Affects open files, ephemeral ports

- **iptables / Connection Tracking**
  - iptables needs to allow two-way communication through the firewall
  - Needs to track connections
  - Keeps a list of connections, whose state is kept in a list
  - The list may not exceed a given limit
  - Will lead to silent failures if it does
Dissecting the Network Mode (4) / How to tune a frequent-access Linux server?

• „nf_conntrack_tcp_timeout_established“
  – Timeout for established connections
  – Has very high default value of 432000 seconds

• Saturation of server by many simultaneous connections
  – De-Serialization in C++ (using Boost.Serialization) may be very costly
  – Must make sure (de-)serialization is disconnected from accepting new connections, or the server may not be responsive

• Queue-flooding in pull-mode
  – Where a timeout is reached, work items may need to be resubmitted.
  – Resubmission happens through a queue
  – Where timeout-values are not coupled (correctly) to the average compute time of clients, the queue will be flooded with work items
  – Need to make sure consumption rate is higher than submission rate
In summary, problems relate to ...

- TCP/IP oddities
- Firewall deficiencies
- Internal architecture of Geneva

→ Not an easy problem
→ Need to reduce complexity!
→ Current design goal: Use a Websocket-type server architecture. May solve MANY of the above problems
Websockets (1)

• **Client never disconnects**
  – Reduces complexity on the TCP level
  – Reduces overhead for handshakes
  – May even allow a push-mode, without fear of queue-flooding
  – May inform clients about shutdowns (formerly they would have to terminate, when the server became unreachable)

• **Must deal with TCP-timeouts**
  – “Paylod-communication“ may still only happen in very long intervals, as the client may just sit there, doing calculations
  – Will need a „heart-beat“
Websockets (2)

• Current implementation derived from „eidheim / Simple-Websocket-Server“ (see https://github.com/eidheim/Simple-WebSocket-Server )
  – MIT-licensed
  – Based on Boost.ASIO
  – Pure C++11

• Removed the pure „Websocket“ part, but kept part of the architecture
Websockets (3)

• Communication now happens on two levels:
  – Administrative (initial hand-shake, keep-alive in regular intervals)
  – Payload (exchange of work-items and results)
• Payload-protocol is implemented on top of the message-transfer
• Administrative and payload-messages enter the same queue ➔ submission in the order they entered the queue
• Payload processing needs to happen in own thread-pool to keep client and server responsive
Summary

• High-throughput / high frequency TCP communication in C++ is CHALLENGING
• Current Design seems to be far more responsive
• Not yet part of a stable release
• Needs further tests
• Will be part of Geneva 2.0, which also represents a major redesign (C++14, simpler creation of new optimization algorithms, Broker-only architecture for parallelization, ...
Thanks to the audience and the GSI team!

If you want to try Geneva:

http://launchpad.net/geneva

You may reach us at

contact@gemfony.eu

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