Parametric Optimization with Evolutionary Strategies in Particle Physics

- Physics Motivation
- Tools
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Physics Motivation – Optimization of Particle Signals

- Signal in histogram resulting from cuts
- Varying cuts can lead to improved signal
- With figure of merit $= f(\text{cuts})$:
  Accessible to computerized maximization techniques
- Often used: $\text{Significance}^2: S^2 = \frac{N^2}{(N + 2B_0)}$
- In comparison: signal / background BAD!
- Problem: Testing quality of cuts in particle physics requires the processing of huge amounts of data for each set of cuts

"Events" → Analysis / Cuts → Histogram with signal → Optimization → e.g. reduced Background

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Physics Motivation – Dalitzplot Analysis at CB/ELSA (Bonn)

Dalitz plot analysis:
- In three-body final state: only two independent variables needed to describe final state; e.g. $p\gamma \rightarrow p\pi^0\eta$
- Choose squared invariant masses of each two of the three particles
- Information about resonant intermediate states can be deducted from band structures, e.g. $a_0 \rightarrow \pi^0\eta$

Procedure
- Start with measured data + phase space distributed MC events
- Fill weight=f(masses, widths, ...) into Dalitz plot for each MC event
- Vary free parameters, minimize $\chi^2$ (masses, widths, ...) - i.e. „difference“ between data- and MC plot; extract parameters
- Problem: large amounts of data make calculation computationally expensive
Tools – Evolutionary Strategies

- Local optima not a problem (e.g. noisy input data ...)
- Can be easily parallelized
- Suitable even for very large optimization tasks
- Non-continuous evaluation functions possible
- More function calls than standard procedures for low number of variables and easy evaluation function

\[ f(x,y) = (\cos(x^2+y^2)+2)(x^2+y^2) \]
\[ \sigma = 1.0 \]

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Tsukuba, Dec. 1st, 2003
Tools – The EVA library

- Implementation of Evolutionary Strategies and Genetic Algorithms
- Parallel Execution on SMP (POSIX threads), clusters and Grid (through MPICH) possible
- In MPI-mode: data exchange through XML
- Seemless parallelization – no change of user code required
- Serial mode allows easy debugging
- Implemented in C++
- Derivative of STL vector class, hence fully templatized
- Open Source
- Interface to ROOT
- In idealized environment: reduction of compute time from over 5 hours to under 3 minutes (1+128 ES)
- Almost linear speedup

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Results – BaBar / Optimizing Significance

- Variation of 4 parameters ($\cos(\Theta_h)$, $D_s$ momentum, mass constraints, fit probability)
- Improved significance of $D_s$ peaks between 19.4% and 45% in different decay channels
- Reduction of compute time from 38 to under 3 hours by parallelization (1+20 ES)
Results – CB/Elsa / Dalitz plot analysis

- Variation of 16 free parameters of (simplified) weight function

\[ W = R_{ph.ep}^2 + R_{\Delta_{10}}^2 \left| BW \left( m_{\Delta}, \Gamma_{\Delta} \right) Y_1^0 \left( \Theta_{\Delta}, \Phi_{\Delta} \right) \right|^2 + R_{\Delta_{11}}^2 \left| BW \left( m_{\Delta}, \Gamma_{\Delta} \right) Y_1^1 \left( \Theta_{\Delta}, \Phi_{\Delta} \right) \right|^2 + R_{s_{11}}^2 \left| BW \left( m_{s_{11}}, \Gamma_{s_{11}} \right) \right|^2 + R_{s_{21}}^2 \left| BW \left( m_{s_{21}}, \Gamma_{s_{21}} \right) \right|^2 + R_{s_{31}}^2 \left| BW \left( m_{s_{31}}, \Gamma_{s_{31}} \right) \right|^2 + R_{\eta_{12}}^2 \left| BW \left( m_{\eta_{12}}, \Gamma_{\eta_{12}} \right) \right|^2 + R_{\eta_{22}}^2 \left| BW \left( m_{\eta_{22}}, \Gamma_{\eta_{22}} \right) \right|^2 + R_{\eta_{32}}^2 \left| BW \left( m_{\eta_{32}}, \Gamma_{\eta_{32}} \right) \right|^2 + R_{\eta_{42}}^2 \left| BW \left( m_{\eta_{42}}, \Gamma_{\eta_{42}} \right) \right|^2 \]

- Very good agreement of MC and data after the ES-based fit
Results – Comparison with Gradient Descent (D.P. analysis)

- Particle physics: Minuit is most common tool (gradient descent)
- Principle: Search for direction of steepest descent
- Disadvantage of G.D.: Very susceptible to local optima
- Advantage of G.D.: Sometimes fewer function calls needed than ES

![Graph showing comparison between Minuit and ES in Particle physics context.](image)
Conclusion

- Automated optimization of particle signals shows very good results even when starting with hand-optimized cuts
- Dalitz plot analysis benefits from parallel execution
- The EVA library, by virtue of parallel execution, makes also those problems accessible to optimization that so far were deemed too computationally expensive
- The EVA library can be used for almost generic small or large optimization problems, in- or outside physics (example: optimization of urban traffic)
- Code will be made available under an Open Source license in a few weeks
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