Performance Optimization: Simulation and Real Measurement

Josef Weidendorfer

KDE Developer Conference 2004
Ludwigsburg, Germany

Agenda

- Introduction
- Performance Analysis
- Profiling Tools: Examples & Demo
- KCachegrind: Visualizing Results
- What’s to come …

Introduction

- Why Performance Analysis in KDE ?
  - Key to useful Optimizations
  - Responsive Applications required for Acceptance
  - Not everybody owns a P4 @ 3 GHz

- About Me
  - Supporter of KDE since Beginning (“KAbalone”)
  - Currently at TU Munich, working on Cache Optimization for Numerical Code & Tools

Agenda

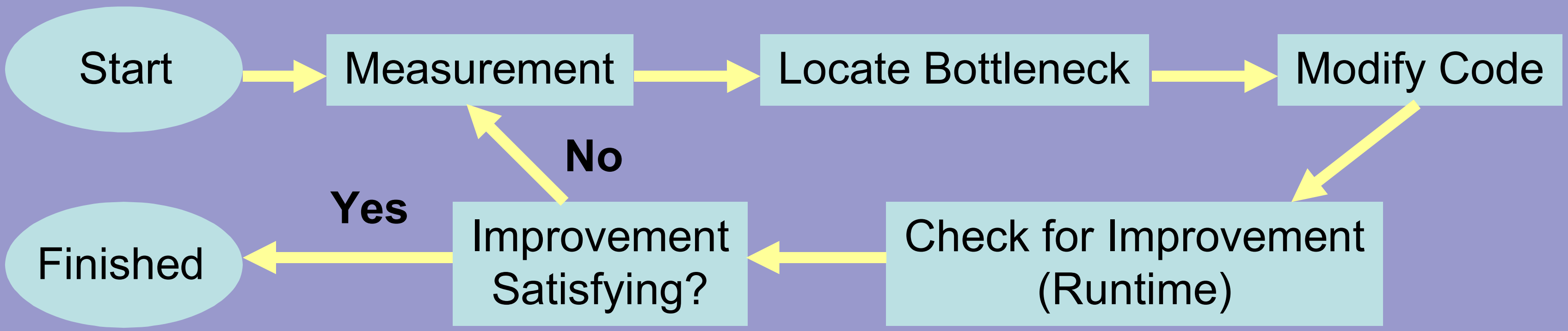
- Introduction
- Performance Analysis
  - Basics, Terms and Methods
  - Hardware Support
- Profiling Tools: Examples & Demo
- KCachegrind: Visualizing Results
- What's to come …

Performance Analysis

- Why to use…
  - Locate Code Regions for Optimizations (Calls to time-intensive Library-Functions)
  - Check for Assumptions on Runtime Behavior (same Paint-Operation multiple times?)
  - Best Algorithm from Alternatives for a given Problem
  - Get Knowledge about unknown Code (includes used Libraries like KDE-Libs/QT)

Performance Analysis (Cont’d)

- How to do…
  - At End of (fully tested) Implementation
  - On Compiler-Optimized Release Version
  - With typical/representative Input Data
  - Steps of Optimization Cycle



Performance Analysis (Cont'd)

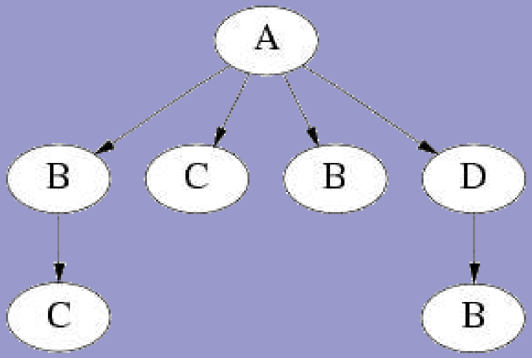
- Performance Bottlenecks (sequential)
  - Logical Errors: Too often called Functions
  - Algorithms with bad Complexity or Implementation
  - Bad Memory Access Behavior (Bad Layout, Low Locality) ← Too low-level for GUI Applications ?
  - Lots of (conditional) Jumps, Lots of (unnecessary) Data Dependencies, ...

Performance Measurement

- Wanted:
  - Time Partitioning with
    - Reason for Performance Loss (Stall because of…)
    - Detailed Relation to Source (Code, Data Structure)
  - Runtime Numbers
    - Call Relationships, Call Numbers
    - Loop Iterations, Jump Counts
  - No Perturbation of Results b/o Measurement

Measurement - Terms

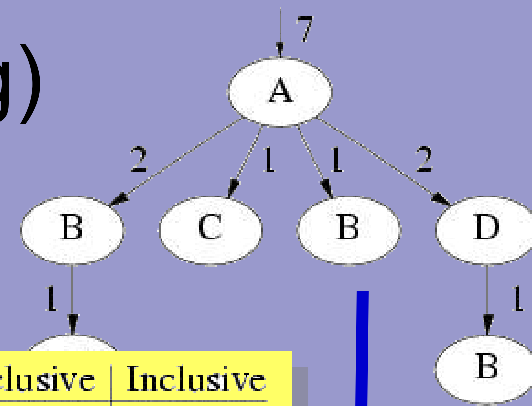
- Trace: Stream of Time-Stamped Events
  - Enter/Leave of Code Region, Actions, …
    Example: Dynamic Call Tree

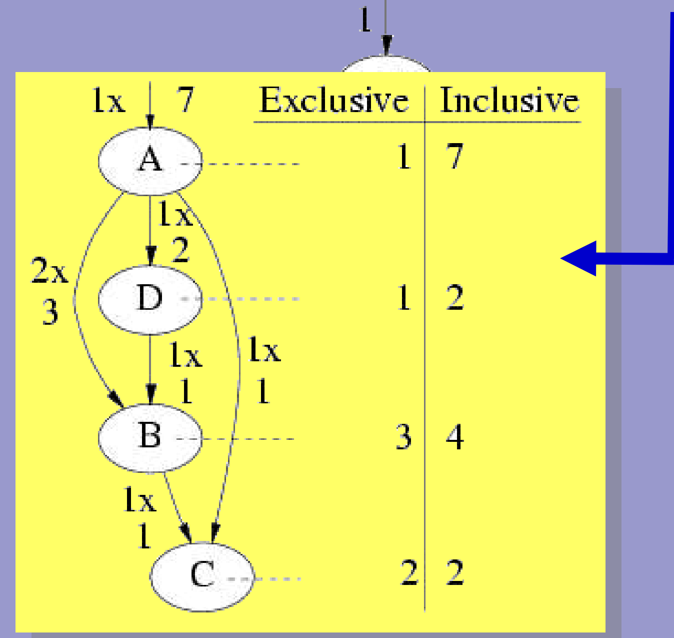


  - Huge Amount of Data (Linear to Runtime)
  - Unneeded for Sequential Analysis (?)

Measurement – Terms (Cont'd)

- Profiling (e.g.Time Partitioning)
  - – Summary over Execution
    - Exclusive, Inclusive Cost / Time, Counters
    - Example:
      DCT → DCG
      (Dynamic Call Graph)
  - – Amount of Data
    Linear to Code Size





Methods

- Precise Measurements
  - Increment Counter (Array) on Event
  - Attribute Counters to
    - Code / Data
  - Data Reduction Possibilities
    - Selection (Event Type, Code/Data Range)
    - Online Processing (Compression, …)
  - Needs Instrumentation (Measurement Code)

Methods - Instrumentation

- – Manual
- – Source Instrumentation
- – Library Version with Instrumentation
- – Compiler
- – Binary Editing
- – Runtime Instrumentation / Compiler
- – Runtime Injection

Methods (Cont'd)

- Statistical Measurement ("Sampling")
  - TBS (Time Based), EBS (Event Based)
  - Assumption: Event Distribution over Code Approximated by checking every N-th Event
  - Similar Way for Iterative Code: Measure only every N-th Iteration
- Data Reduction Tunable
  - Compromise between Quality/Overhead

Methods (Cont'd)

- Simulation
  - Events for (not existant) HW Models
  - Results not influenced by Measurement
  - Compromise Quality / Slowdown
    - Rough Model = High Discrepancy to Reality
    - Detailed Model = Best Match to Reality
      But: Reality (CPU) often unknown…
  - Allows for Architecture Parameter Studies

Hardware Support

- Monitor Hardware
  – Event Sensors (in CPU, on Board)
  – Event Processing / Collection / Storing
    - Best: Separate HW
    - Comprimise: Use Same Resources after Data Reduction
  – Most CPUs nowadays include Performance Counters

Performance Counters

- Multiple Event Sensors
  - ALU Utilization, Branch Prediction,
    Cache Events (L1/L2/TLB), Bus Utilization
- Processing Hardware
  - Counter Registers
    - Itanium2: 4, Pentium-4: 18, Opteron: 8
      Athlon: 4, Pentium-II/III/M: 2, Alpha 21164: 3

Performance Counters (Cont'd)

- Two Uses:
  - Read
    - Get Precise Count of Events in Code Regions by Enter/Leave Instrumentation
  - Interrupt on Overflow
    - Allows Statistical Sampling
    - Handler Gets Process State & Restarts Counter
- Both can have Overhead
- Often Difficult to Understand

Agenda

- Introduction
- Performance Analysis
- Profiling Tools: Examples & Demo
  - Callgrind/Calltree
  - OProfile
- KCachegrind: Visualizing Results
- What's to come …

Tools - Measurement

- Read Hardware Performance Counters
  - Specific: **PerfCtr** (x86), Pfmon (Itanium), perfex (SGI)
    Portable: PAPI, PCL
- Statistical Sampling
  - PAPI, Pfmon (Itanium), **OProfile** (Linux),
    VTune (commercial - Intel), Prof/GProf (TBS)
- Instrumentation
  - GProf, Pixie (HP/SGI), VTune (Intel)
  - DynaProf (Using DynInst), **Valgrind** (x86 Simulation)

Tools – Example 1

- GProf (Compiler generated Instr.):
  - Function Entries increment Call Counter for (caller, called)-Tupel
  - Combined with Time Based Sampling
  - Compile with “gcc –pg ...”
  - Run creates “gmon.out”
  - Analyse with “gprof ...”
  - Overhead still around 100% !
- Available with GCC on UNIX

Tools – Example 2

- Callgrind/Calltree (Linux/x86), GPL
  - Cache Simulator using Valgrind
  - Builds up Dynamic Call Graph
  - Comfortable Runtime Instrumentation
  - http://kcachegrind.sf.net
- Disadvantages
  - Time Estimation Inaccurate
    (No Simulation of modern CPU Characteristics!)
  - Only User-Level

Tools – Example 2 (Cont'd)

- Callgrind/Calltree (Linux/x86), GPL
  - Run with "callgrind prog"
  - Generates "callgrind.out.xxx"
  - Results with "callgrind_annotate" or "kcachegrind"
  - Cope with Slowness of Simulation:
    - Switch of Cache Simulation: --simulate-cache=no
    - Use "Fast Forward":
--instr-atstart=no / callgrind_control –i on
- DEMO: KHTML Rendering…

Tools – Example 3

- **OProfile**
  - Configure (as Root: oprof_start, ~/.oprofile/daemonrc)
  - Start the OProfile daemon (opcontrol -s)
  - Run your code
  - Flush Measurement, Stop daemon (opcontrol –d/-h)
  - Use tools to analyze the profiling data
    `opreport`: Breakdown of CPU time by procedures
    (better: opreport –gdf | op2calltree)
- DEMO: KHTML Rendering…

Agenda

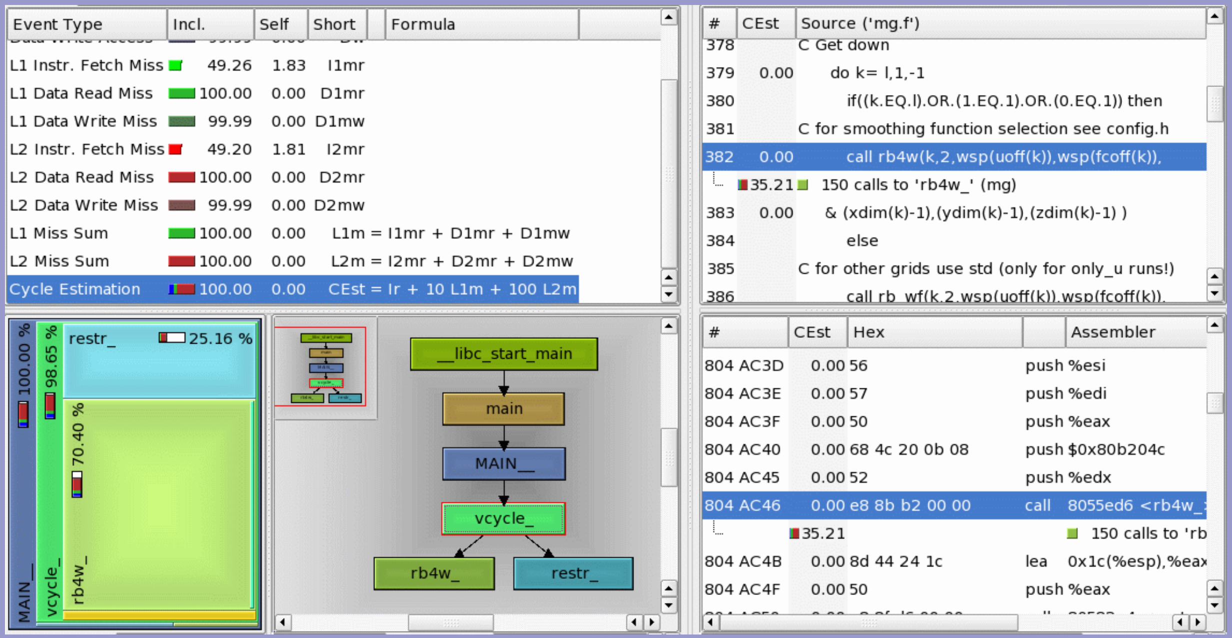
- Introduction
- Performance Analysis
- Profiling Tools: Examples & Demo
- KCachegrind: Visualizing Results
  - Data Model, GUI Elements, Basic Usage
  - DEMO
- What's to come …

KCachegrind – Data Model

- Hierarchy of Cost Items (=Code Relations)
  - Profile Measurement Data
  - Profile Data Dumps
  - Function Groups:
    Source files, Shared Libs, C++ classes
  - Functions
  - Source Lines
  - Assembler Instructions

KCachegrind – GUI Elements

- List of Functions / Function Groups
- Visualizations for an Activated Function
- DEMO



Agenda

- Introduction
- Performance Analysis
- Profiling Tools: Examples & Demo
- KCachegrind: Visualizing Results
- What’s to come …
  - Callgrind
  - KCachegrind

What's to come

- Callgrind
  - Free definable User Costs
    ("MyCost += arg1" on Entering MyFunc)
  - Relation of Events to Data Objects/Structures
  - More Optional Simulation (TLB, HW Prefetch)

What's to come (Cont'd)

- KCachegrind
  - Supplement Sampling Data with Inclusive Cost via Call-Graph from Simulation
  - Comparation of Measurements
  - Plugins for
    - Interactive Control of Profiling Tools
    - Visualizations
- Visualizations for Data Relation

Finally…

THANKS FOR LISTENING