Towards an Energy-Aware Scientific I/O Interface

Stretching the ADIOS Interface to Foster Performance Analysis and Energy Awareness

Julian M. Kunkel, Timo Minartz, Michael Kuhn, Thomas Ludwig

julian.martin.kunkel@informatik.uni-hamburg.de

Scientific Computing
Department of Informatics
University of Hamburg

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1. Introduction
2. ADIOS
3. CIAO interface
4. Benefit for analysis tools
5. Fostering energy efficiency
6. Summary

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Motivation

Conserving energy

- Hardware components can be put into a low power state.
  - But transitions between power states are time consuming.
- Intelligent switching of states is important.
  - Avoid (minimize) slow down of programms.
  - Induced noise endangers synchronization of processes.

Intelligent switching of states

- Knowledge of future program activity is required.
- Automatic vs. manual switching.
  - The OS has little information about future activity.
  - Developers have an idea about the program.

Motivation

Problem of manual annotation

- Convince developers to use the “new” interface is hard.
  - Benefit vs. work.
- Tedious work to annotate
  - Also, the developer must think about future activity.
- Error-prone
  - Sometimes manual annotations are incorrect.

Proposed solution

Extend an existing I/O interface to support **annotated phases**.
A library **analyzes** phases at runtime and **controls** hardware.

Phases

Phase concept

- Phases span a longer period of execution and achieves a goal.
  - Across multiple function calls, or just a part of a loop.
- Names encode high-level semantics.
  - “Pre-processing”, “Input of topological data”, “iteration”...
- The same name can be used to encode similar behavior.
  - “Exchange-neighbour ghost cells”

Extension of an existing I/O interface

Benefit of the extended interface/library

- Improve knowledge to estimate phase time – optimize I/O.
  - Caching and background optimizations get more time.
- Available phase information can be given to performance tools.
  - Performance analysis is enriched with phase information.
- Automatic control of power states in the devices.
  - Reduce energy consumption.

Adaption of the interface

Threefold benefit of the light-weight interface might convince users.

1. Introduction
2. **ADIOS**
3. CIAO interface
4. Benefit for analysis tools
5. Fostering energy efficiency
6. Summary

Introduction of ADIOS

Adaptable IO System

- Alternative high-level I/O interface.
  - Annotations of variables similar to HDF5.
- Offers various back-ends: POSIX, MPI-IO, NULL or in-situ vis.
- BP file format.
  - Throughput oriented, avoids synchronization.
  - An ADIOS file may be represented by one or multiple objects.
  - Easy conversion of BP files into NetCDF or HDF5.
- XML specification of variables and run-time parameters.
  - Adapt programs to the site’s file system without code adjustment.
  - Translate XML into C or Fortran code to read/write data.

Listing 1: Sketched ADIOS code

```
    int NX = 10, NY = 10, NZ = 100;  double matrix[NX][NY][NZ];
    MPI_Comm comm = MPI_COMM_WORLD; int64_t adios_handle;
    int adios_err; uint64_t adios_groupsize, adios_totalsize;

    MPI_Init(&argc, &argv); MPI_Comm_rank(comm, &rank);
    adios_init("example.xml");

    for (t = 0; t < 10 ; t++) {
      adios_start_calculation();
      /* computation */
      adios_stop_calculation();
      /* MPI communication */
      adios_open(&adios_handle, "fullData", "testfile.bp", t == 0 ? "w": "a", &comm);
#include "gwrite_fullData.ch"
      adios_close(adios_handle);
      /* indicate progress for write-behind */
      adios_end_iteration();
    }

    adios_finalize(rank); MPI_Finalize(); return 0;
```

Listing 2: ADIOS example code – gwrite_fullData.ch

```
adios_groupsize = 4 \
                + 4 \
                + 4 \
                + 8 * (NX) * (NY) * (NZ);
adios_group_size (adios_handle, adios_groupsize, &adios_totalsize);
adios_write (adios_handle, "NX", &NX);
adios_write (adios_handle, "NY", &NY);
adios_write (adios_handle, "NZ", &NZ);
adios_write (adios_handle, "matrix_data", matrix);
```

This code is automatically generated from the XML.

Efficient I/O

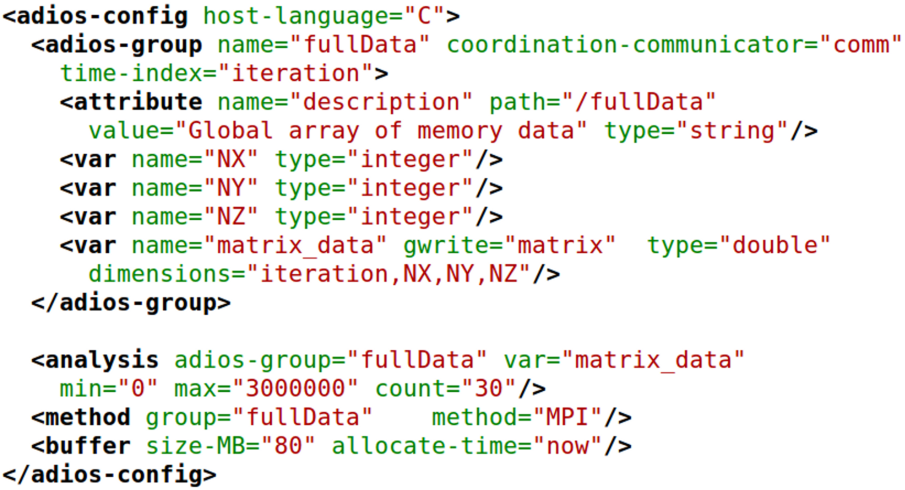
Caching

- ADIOS aggressively caches data.
- Write-behind during compute phases.
- Function call indicates the speed of iterative programs.

User control in the XML

- Pick the best suitable backend for a supercomputer and task.
- Set optimal parameters such as the cache size.
- Instruct to create derived data (histograms).

ADIOS XML code



```
<adios-config host-language="C">
  <adios-group name="fullData" coordination-communicator="comm"
    time-index="iteration">
    <attribute name="description" path="/fullData"
      value="Global array of memory data" type="string"/>
    <var name="NX" type="integer"/>
    <var name="NY" type="integer"/>
    <var name="NZ" type="integer"/>
    <var name="matrix_data" gwrite="matrix"  type="double"
      dimensions="iteration,NX,NY,NZ"/>
  </adios-group>

  <analysis adios-group="fullData" var="matrix_data"
    min="0" max="3000000" count="30"/>
  <method group="fullData"    method="MPI"/>
  <buffer size-MB="80" allocate-time="now"/>
</adios-config>
```

1 Introduction

2 ADIOS

3 CIAO interface

4 Benefit for analysis tools

5 Fostering energy efficiency

6 Summary

CIAO interface

Extension to ADIOS

- “CIAO” is used to refer to the modified functions.
- Classification into calculation, communication and I/O phases.
  - Add names to phases.
- Goal: Trigger power state and I/O behavior if its advantageous.
  - It is necessary to **predict** future activity!

Listing 3: CIAO example code

```
adios_init("example.xml");

ciao_open(...);
/* read input */
ciao_close(...);

ciao_start_calculation("pre-processing");
/* pre-process input */
ciao_end_calculation();

for (t = 0; t < 10 ; t++) {
  ciao_start_calculation("iteration");
  /* computation */
  ciao_end_calculation();

  ciao_start_communication("exchange-neighbour");
  /* communication */
  ciao_end_communication();

  ciao_open(&adios_handle, "fullData", "testfile.bp", t == 0 ?
       ↪ "w": "a", &comm);
#include "gwrite_fullData.ch"
  ciao_close(adios_handle);
}
adios_finalize(rank);
```

Prediction of future activity

Characterization of phases

- Characterize every named phase:
  - Time, performance (CPU, memory, network utilization).
  - This also enables to classify the phases automatically!

Prediction of phase characteristics

- Characteristics of repeated invocation might be similar.
- Use old characteristics to predict the current phase with:
  - Historic knowledge across program runs.
  - Average (or worst case) characteristics.
- The user can offer hints in the XML to set the predictor.

Prediction of future activity

Estimation of program workflow

- But we want to predict more than just the current phase!
- Sequence of phase transitions could be tracked in CIAO.
  - Probably “iteration-compute” is followed by “exchange-ghost”.
- $\Rightarrow$ predict future phases to estimate future utilization.
- Coarse grained problem of branch prediction.

```
<adios-config host-language="C">
  ...
  <buffer size-MB="80" allocate-time="now"/>
  ...
  <estimation debug="statistics">
    <inter-phase method="STOCHASTIC" accept-threshold="95%">
    <phase name="iteration"       method="MIN"/>
    <phase name="post-processing" method="HISTORIC"/>
  <estimation/>
</adios-config>
```

1 Introduction

2 ADIOS

3 CIAO interface

4 Benefit for analysis tools

5 Fostering energy efficiency

6 Summary

Benefit for analysis tools

Phase knowledge enriches profiling and tracing

- Collect an individual profile for each phase.
- Restrict analysis to phases of interest.
- Automatically start tracing/profiling if the phase is interesting.
  - Change in characteristics → interesting.

State of the art

- Phases are already known in performance analysis (TAU, ...)
- But, the information is just used for that purpose.

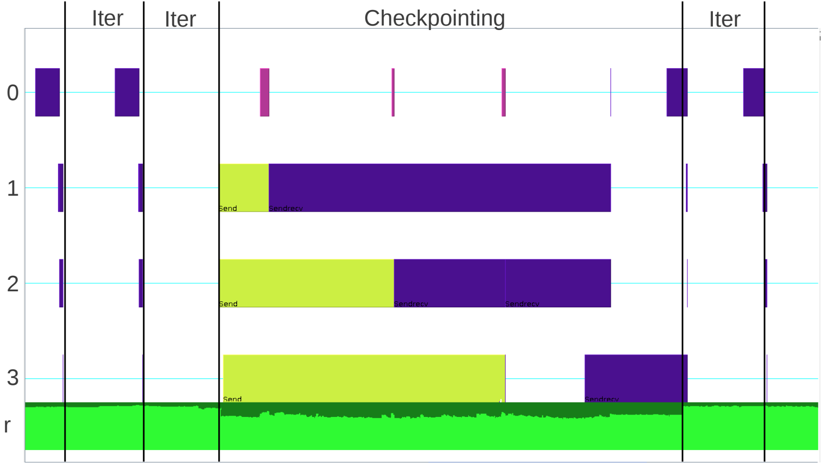


Figure: Tracing MPI activity and node power consumption

1 Introduction

2 ADIOS

3 CIAO interface

4 Benefit for analysis tools

5 Fostering energy efficiency

6 Summary

Fostering energy efficiency

Controlling hardware states

- Knowing characteristics of the phase(s) allows efficient control.
- Usage of devices and duration of the phase can be estimated.
- Utilize eeClust interface to announce this knowledge.

$$t_{phase} = \frac{E_{change}}{P_{diff}} + t_{change} \tag{1}$$

Phases and active components

Phase bottleneck	I/O activity	Network activity	Potential energy savings
Computation	–	Write-behind to I/O servers	I/O and NIC
Communication	–	–	I/O and CPU
Input/Output	Access data and/or buffer data	Read data if necessary	CPU and NIC

1 Introduction

2 ADIOS

3 CIAO interface

4 Benefit for analysis tools

5 Fostering energy efficiency

6 Summary

Summary & Conclusions

- CIAO extends the ADIOS interface.
- Named phases indicate high-level semantics.
- Threefold benefit for the user:
  - Performance
  - Program analysis
  - Energy efficiency
- Monitoring of phase characteristics to steer:
  - I/O behavior
  - Performance analysis tools
  - Hardware power states

Future Work

- Implementation and evaluation of the general concept.
- We seek collaboration to develop/use an open interface!