Runtime Optimization of Application Level Communication Patterns

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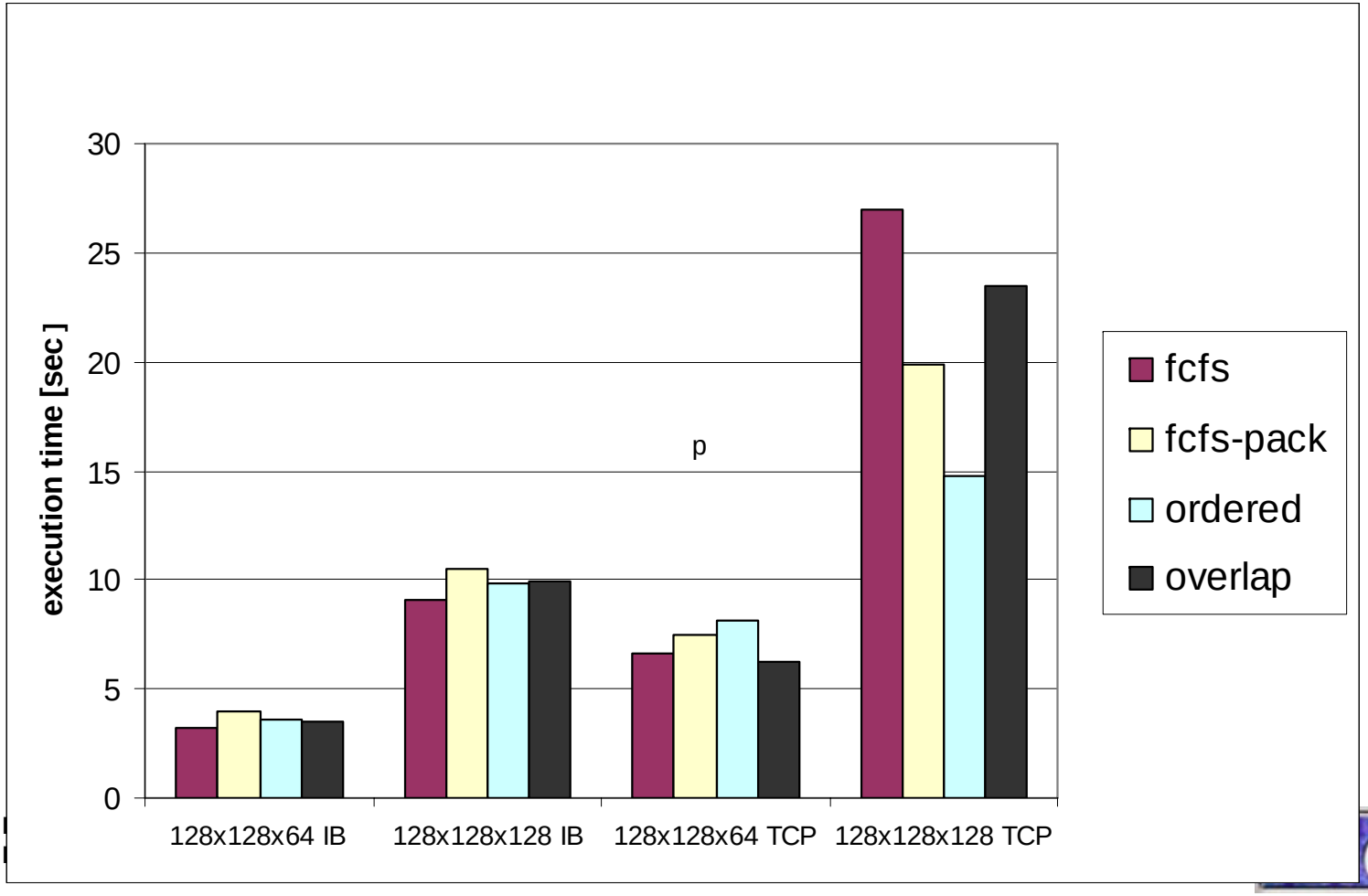
Motivation

Finite Difference code on a PC cluster using IB and GE interconnects
Execution time for 200 iterations of the solver on 32 processes/processors



How to implement the required communication pattern efficiently?

- Dependence on platform
  - Some functionality only supported (efficiently) on certain/platforms or with certain network interconnects
- Dependence on MPI library
  - Does the MPI library support all available methods
  - Efficiency in overlapping communication and computation
  - Quality of the support for user defined data-types
- Dependence on application
  - Problem size
  - Ratio of communication to computation

- **Problem**: How can an (average) user understand the myriad of implementation options and their impact on the performance of the application?
- **(Honest) Answer**: no way
  - Abstract interfaces for application level communication operations required → ADCL
  - Statistical tools required to detect correlations between parameters and application performance

ADCL - Adaptive Data and Communication Library

- Goals:
  - Provide abstract interfaces for often occurring application level communication patterns
    - Collective operations
    - Not-covered by MPI specification
  - Provide a wide variety of implementation possibilities and decision routines which choose the fastest available implementation (at runtime)
- Not replacing MPI, but add-on functionality
  - Uses many features of MPI

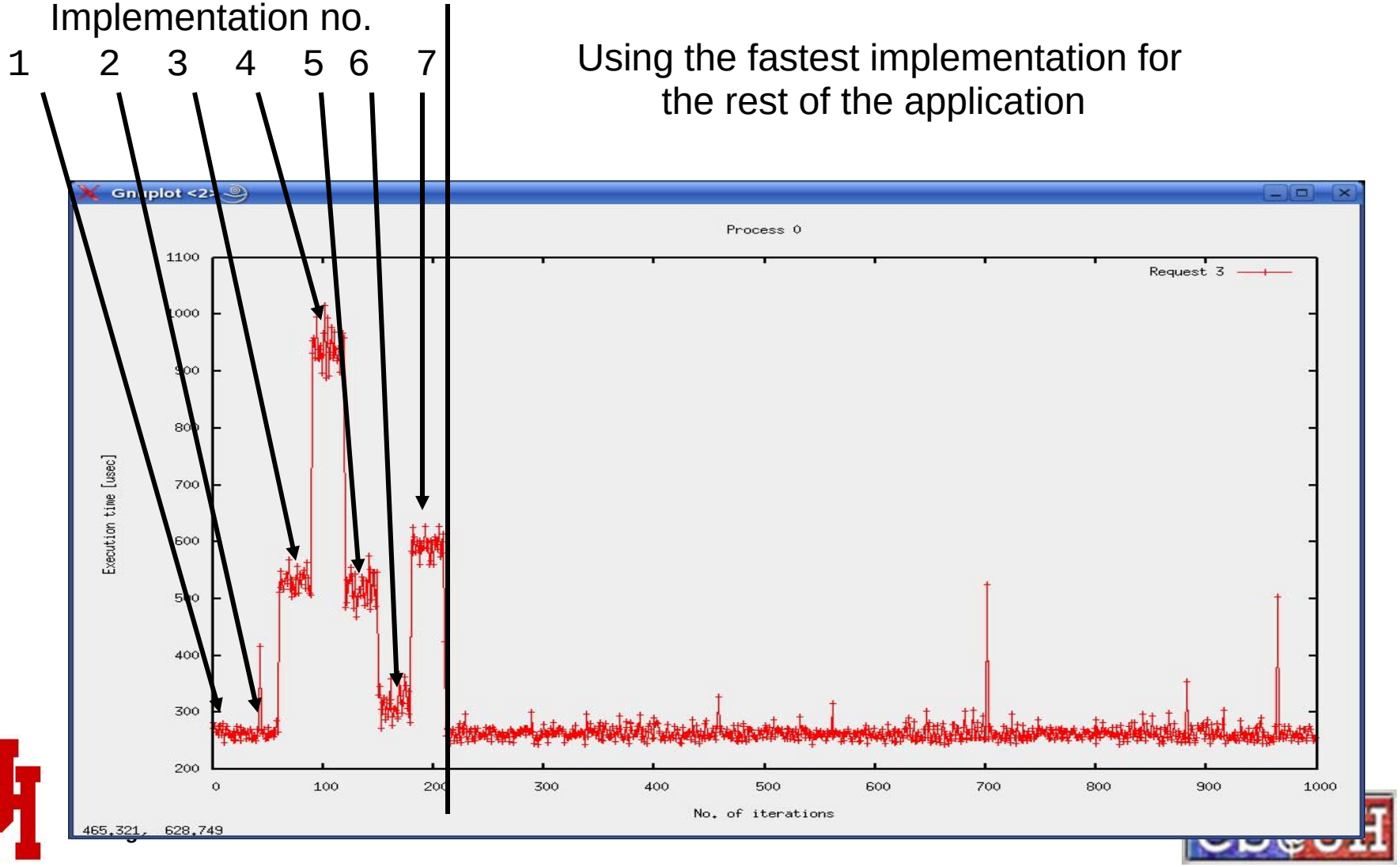
ADCL terminology

ADCL object	Functionality
`Attribute`	Abstraction for a characteristic of an implementation represented by the set its possible values
`Attribute-set`	Group of attributes
`Function`	Implementation of a particular operation • optionally including an attribute-set and values
`Function-set`	Set of functions providing the same functionality • have to have the same attribute-set
`Vector`	Abstraction for a multi-dimensional data object
`Topology`	Abstraction for a process topology
`Request`	Handle for tuple of `< topology, vector, function-set>`

Code sample

```
ADCL_Vector   vec;
ADCL_Topology topo;
ADCL_Request  request;

/* Generate a 2-D process topology */
MPI_Cart_create ( comm, 2, cart_dims, periods, 0,&cart_comm);
ADCL_Topology_create ( cart_comm, &topo );

/* Register a 2D vector with ADCL */
ADCL_Vector_register (ndims, vec_dims, HALO_WIDTH,
                      MPI_DOUBLE, vector, &vec);

/* Match process topology, data item and function-set */
ADCL_Request_create (vec, topo, ADCL_FNCTSET_NEIGHBORHOOD,
                     &request );

for (i=0; i<NIT; i++ ) {
          /* Main application loop */
          ADCL_Request_start (request );
          …
}
```

Runtime selection logic: brute force search (I)



Runtime selection logic: brute force search (II)

- Test each function of a given function set a given number of times
  - Store the execution time for each execution per process
- Filter the list of execution times in order to exclude outliers
- Determine the avg. execution time per function *i* and process *j*
- Determine the max. execution time for function *i* across all processes

$$f_i^{\max} = \max(f_i^j),\ j = 0...nprocs - 1$$

  - Requires communication (e.g. `MPI_Allreduce`)

Runtime selection logic: brute force search (III)

- Determine the function with the minimal max. execution time across all processes

$$f_{winner} = \min(f_i^{\max}), i = 0...nfuncs - 1$$

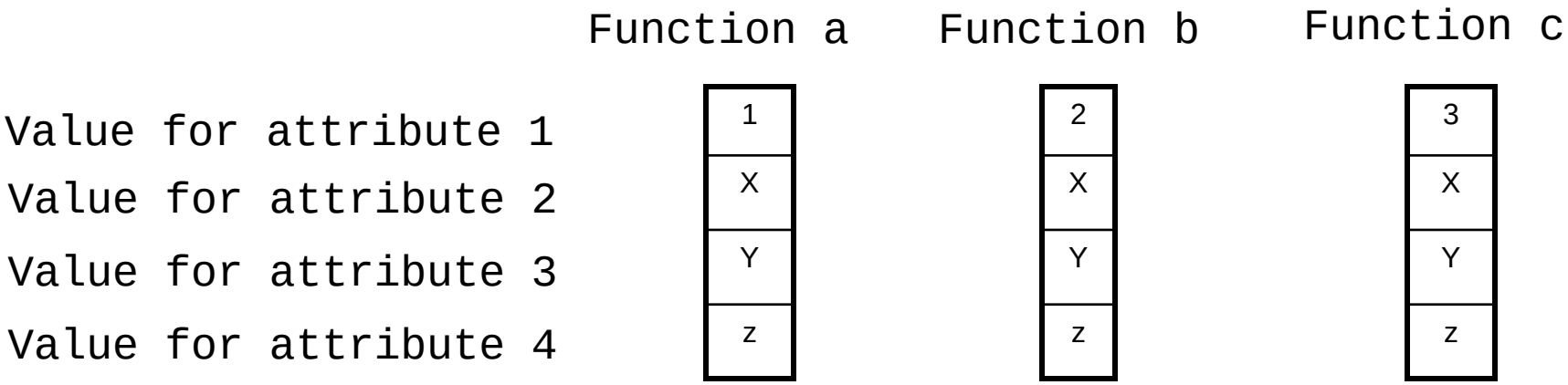
- Use this function for the rest of the application lifetime

Runtime selection logic: performance hypothesis (I)

- Assumptions:
  - every implementation can be characterized by a set of attributes, which impact its performance, e.g. for neighborhood communication
    - Communication pattern/degree
    - Handling of non-contiguous data
    - Data transfer primitive
    - Overlapping communication and computation
  - The fastest implementation will also have the optimal values for these attributes

Runtime selection logic: performance hypothesis (II)

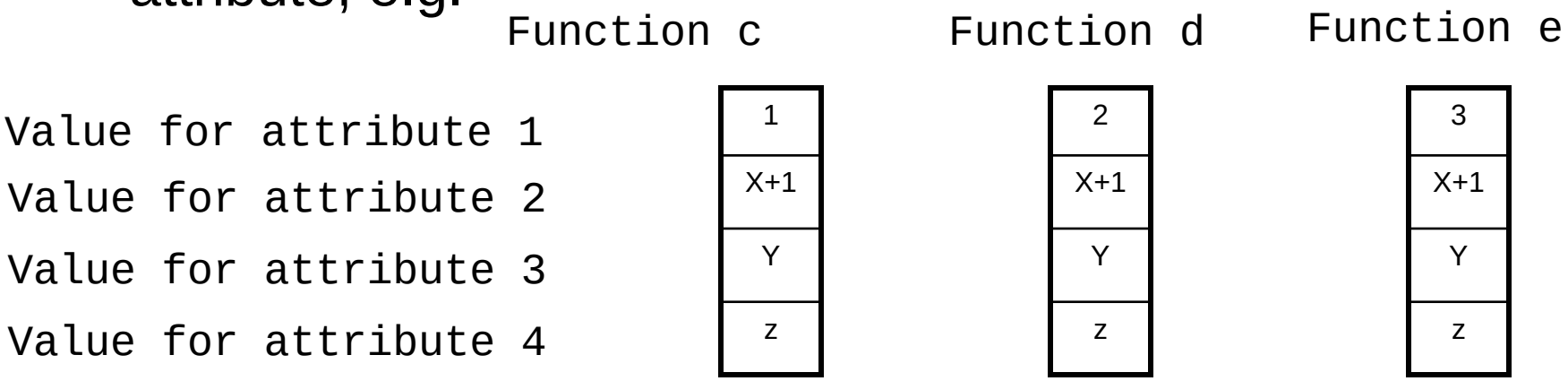
- Approach: determine the optimal value for an attribute by comparing the execution time of functions differing in only a single attribute



  - E.g. if function c had the lowest execution time across all processes:
    - **Hypothesis**: value 3 optimal for attribute 1
    - **Confidence value** in this hypothesis: 1

Runtime selection logic: performance hypothesis (III)

- Evaluate a different set of functions differing in one other attribute, e.g.



  - If this set of measurements lead to the same optimal value for attribute 1:
    - Increase confidence value for this hypothesis by 1
  - Else decrease the confidence value by 1

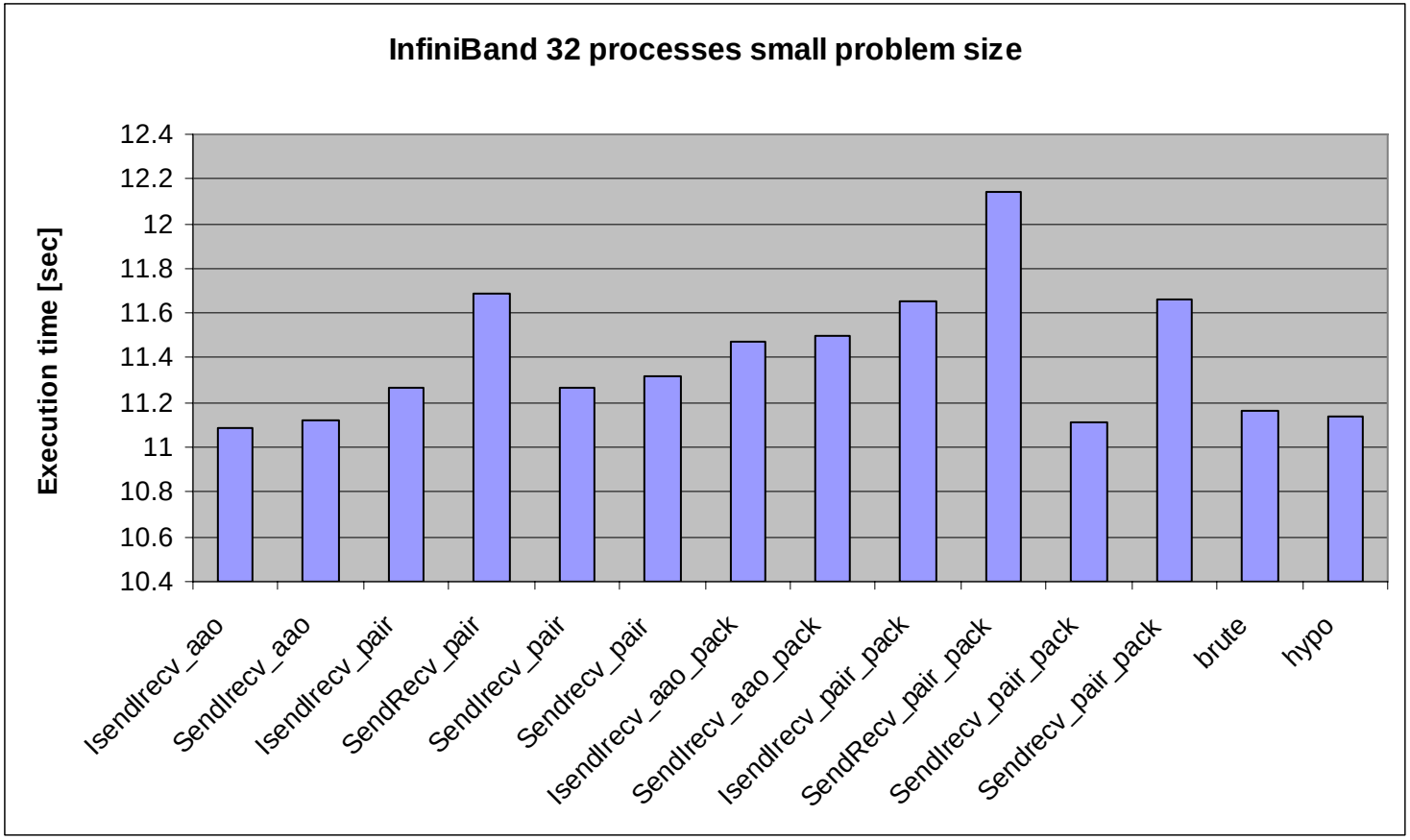
Runtime selection logic: performance hypothesis (IV)

- If the confidence value for an attribute reaches a given threshold
  - Remove all functions not having the required value for this attribute from the Function-set
- If the value for attribute (s) do not converge towards a value this algorithm leads to the brute force search
- Advantage: potentially fewer functions have to be evaluated to determine the winner

Currently available implementations for neighborhood communication

Name	Comm. pattern	Handling of non-cont. data	Data transfer primitive
IsendIrecv_aao	aao	ddt	MPI_Isend/Irecv/Waitall
IsendIrecv_pair	pair	ddt	MPI_Isend/Irecv/Waitall
SendIrecv_aao	aao	ddt	MPI_Send/Irecv/Waitall
SendIrecv_pair	pair	ddt	MPI_Send/Irecv/Wait
IsendIrecv_aao_pack	aao	ddt	MPI_Isend/Irecv/Waitall
IsendIrecv_pair_pack	pair	Pack/unpack	MPI_Isend/Irecv/Waitall
SendIrecv_aao_pack	aao	ddt	MPI_Send/Irecv/Waitall
SendIrecv_pair_pack	pair	Pack/unpack	MPI_Send/Irecv/Wait
SendRecv_pair	pair	ddt	MPI_Send/Recv
Sendrecv_pair	pair	ddt	MPI_Send/Recv
SendRecv_pair_pack	pair	Pack/unpack	MPI_Send/Recv
Sendrecv_pair_pack	pair	Pack/unpack	MPI_Send/Recv
WinfencePut_aao	aao	ddt	MPI_Put/MPI_Win_fence
WinfenceGet_aao	aao	ddt	MPI_Get/MPI_Win_fence
PostStartPut_aao	aao	ddt	MPI_Put/MPI_Win_post/start
PostStartGet_aao	aao	ddt	MPI_Get/MPI_Win_post/start
WinfencePut_pair	pair	ddt	MPI_Put/MPI_Win_fence
WinfenceGet_pair	pair	ddt	MPI_Get/MPI_Win_fence
PostStartPut_pair	pair	ddt	MPI_Put/MPI_Win_post/start
PostStartGet_pair	pair	ddt	MPI_Get/MPI_Win_post/start

Performance results (I)



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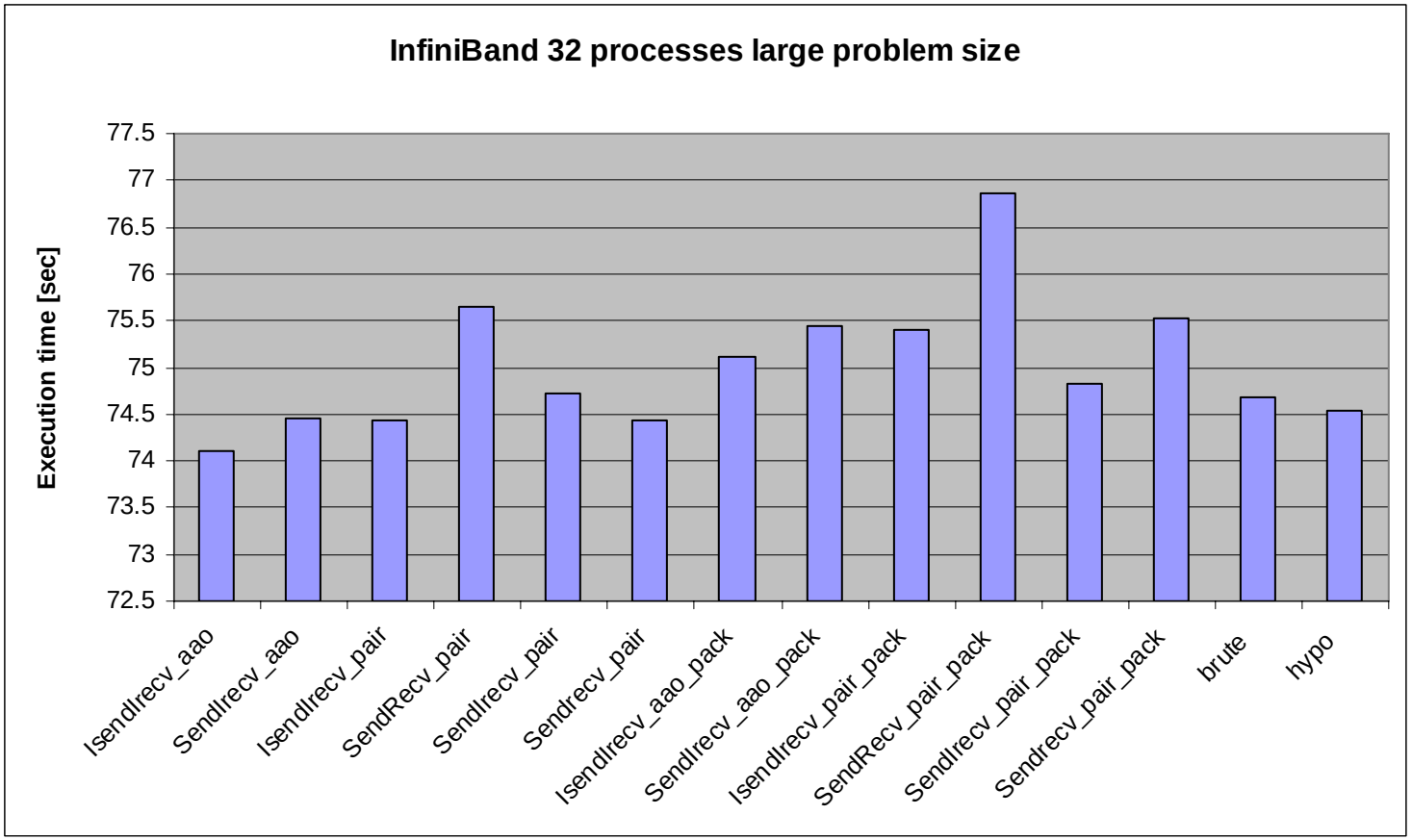
Performance results (II)



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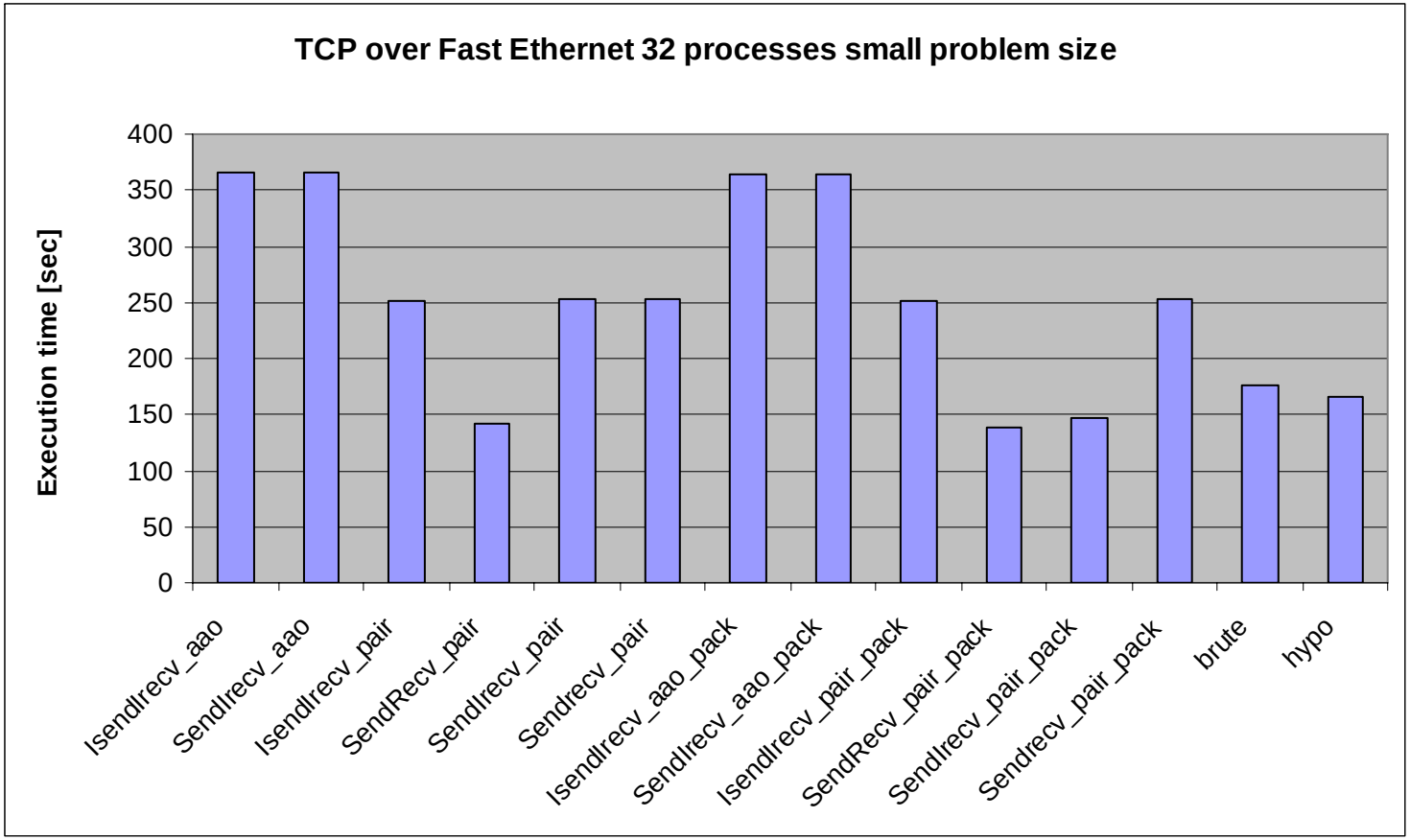
Performance results (III)



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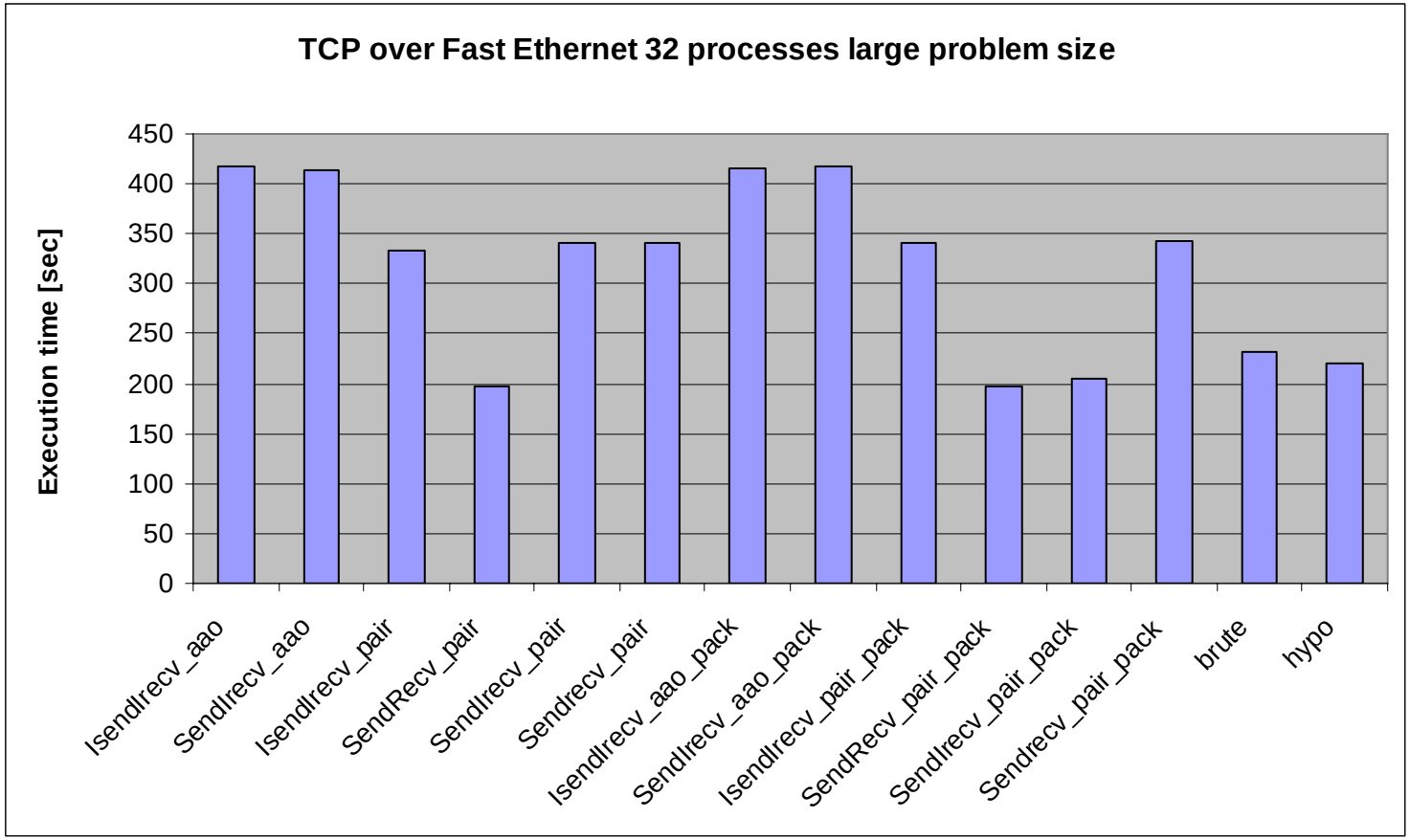
Performance results (IV)



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Limitations of ADCL

- Reproducibility of measurements even on dedicated compute nodes a challenging topic
  - Hyper-threading
  - Processor frequency scaling
- Network often shared between multiple jobs
- Hierarchical networks
  - Process placement by the batch scheduler
- Performance hypothesis
  - Attributes should not be correlated
- User has to modify its code
  - How much longer will we have to deal with MPI?

Advantages of ADCL

- Provides close to optimal performance in many scenarios
- Simplifies the development of parallel code for many applications
- Simplifies the development of adaptive parallel code
- Currently ongoing work:
  - Improving (nearly) all components of ADCL
    - Data filtering
    - Increase parameter space and set of implementation
    - Experiment with other runtime selection algorithms
      - Historic learning, Game theory, genetic algorithms
  - Integration with a CFD solver in cooperation with Dr. Garbey