A Component-Based Framework for the Cell Broadband Engine

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Outline

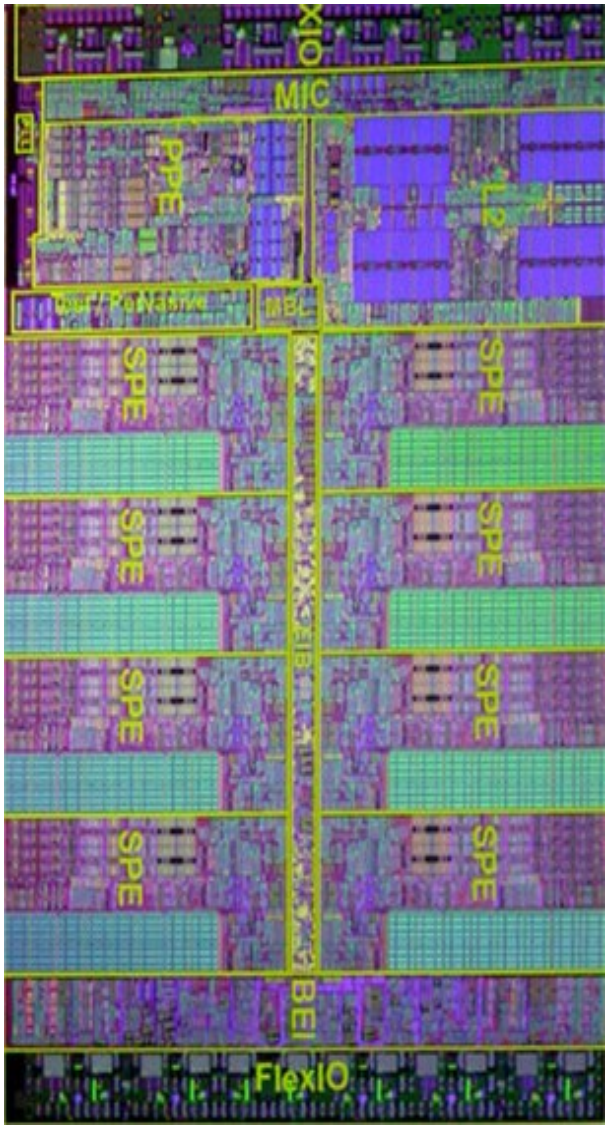
- Motivation
- Contributions
  - CBE Intercore Messaging Library
  - DataCutter-Lite
- Experimental Results
- Conclusions and Future Work

Motivation

- Programming the Cell requires expertise
  - Parallel programming
    - Data decomposition
    - Parallel algorithms
  - Streaming programming
    - Small scratch-pad memories
    - Double buffering
  - Cell peculiarities
    - DMA commands
    - SPE optimizations – not addressed here
- Component-based streaming frameworks are natural fits for heterogeneous, parallel processors

Cell Broadband Engine

- Cell Broadband Engine
  - Designed jointly by Sony, Toshiba, and IBM
  - 9-core heterogeneous microprocessor
  - Integrated high-bandwidth ring bus for on-chip communication
  - Quick Specs
    - >200 GFLOP/s floating-point arithmetic
    - >200 GB/s internal bus bandwidth



Cell Programming Peculiarities

- DMA commands
  - Simple in concept, difficult in practice
  - Fence, barrier, lists, alignments, etc.
- SPE code optimizations*
  - 25 GFLOP/s only reached on SPE when using SIMD FMA commands
  - Static dual-issue scheduling
  - Branch hints

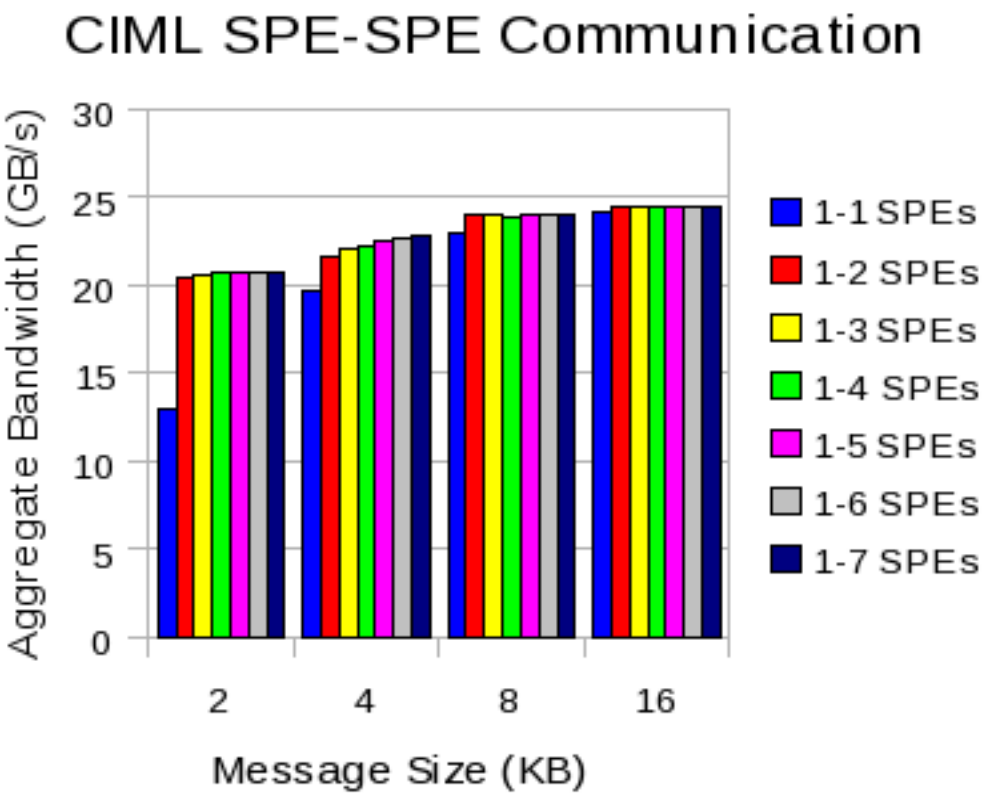
Contributions

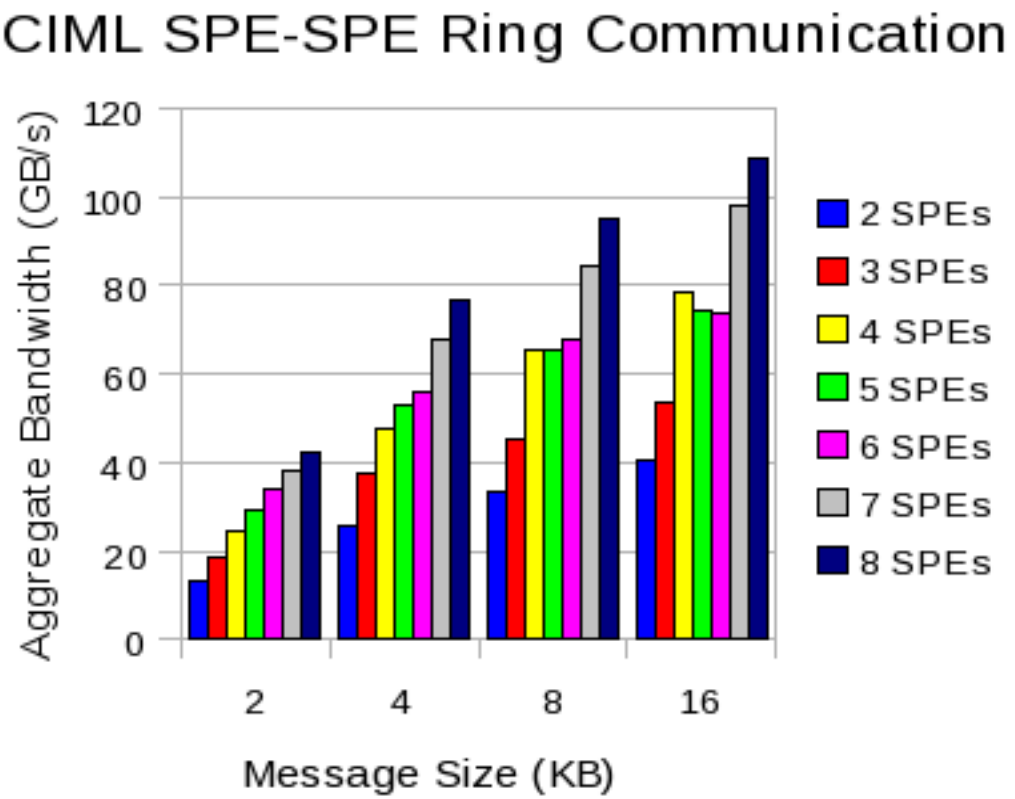
- Cell Broadband Engine Intercore Messaging Library (CIML)
  - Two-sided communication library
- DataCutter-Lite for Cell Broadband Engine
  - Filter-stream programming framework and runtime engine
  - Uses CIML for intercore communication

CBE Intercore Messaging Library (CIML)

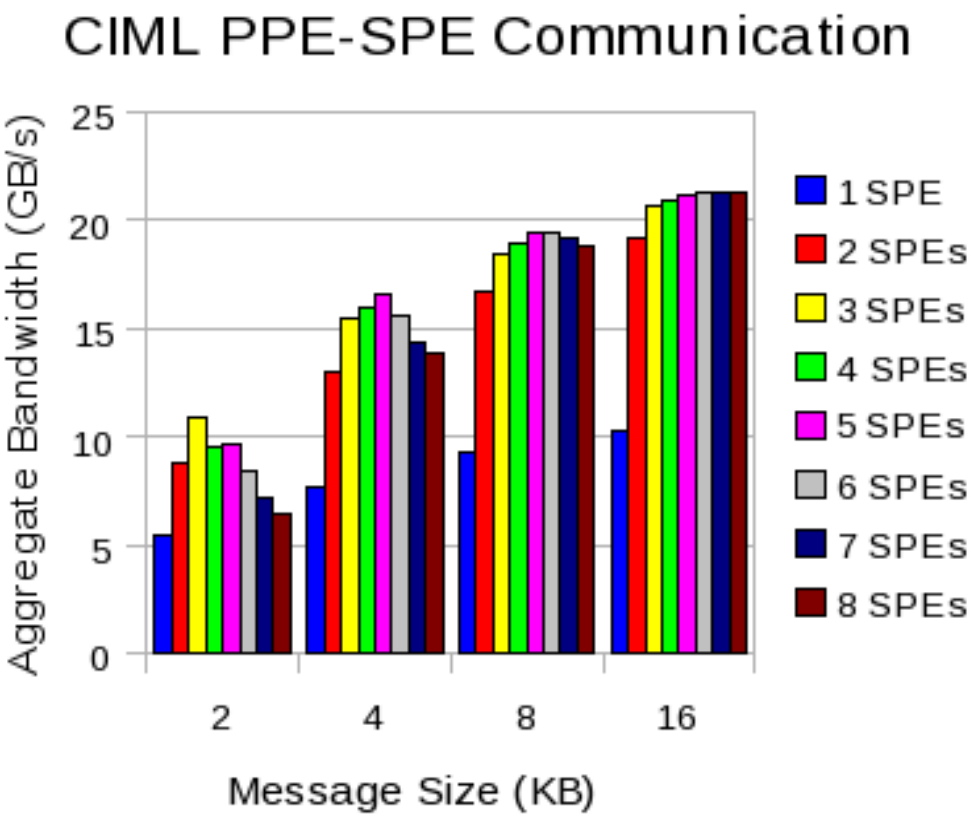
- Two-sided communication library
- Allows two-sided communication between all processors in Cell (PPU and SPU)
- Different from LANL's Cell Messaging Layer
  - CML uses a receiver-initiated protocol
  - Not suitable for streaming frameworks
    - Sender unknown
- Good performance for larger message sizes

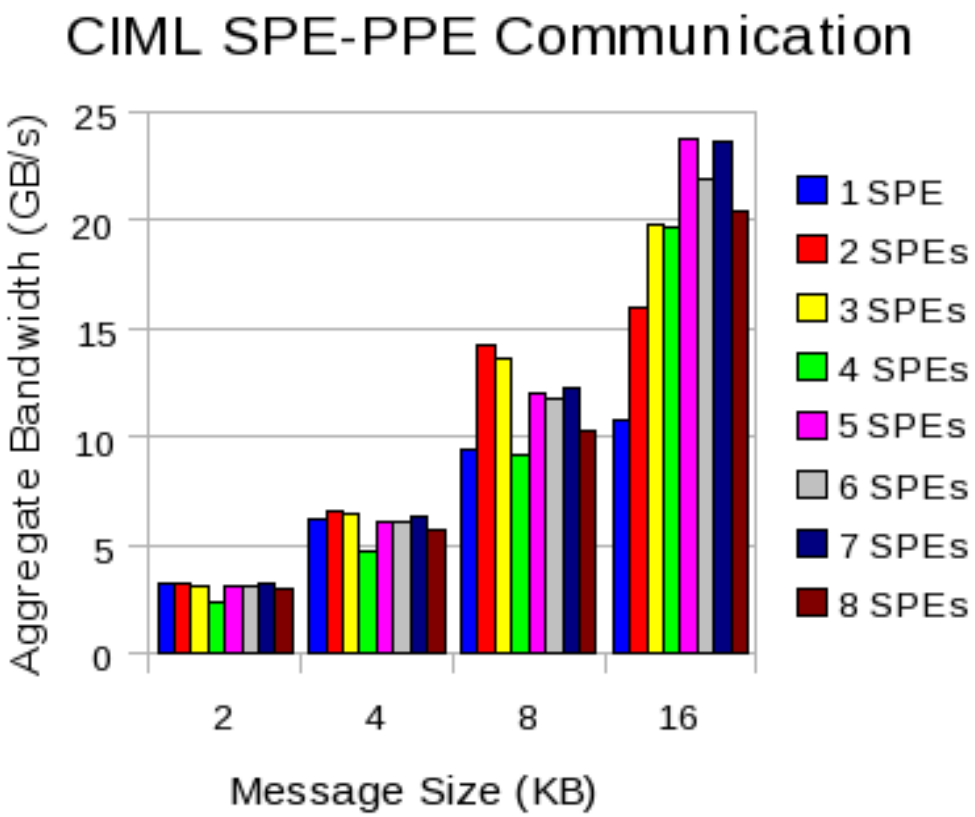
CIML Performance





CIML Performance





Component-based Programming Frameworks

- Application is decomposed into a natural task-graph
  - Task graph performs computation
  - Individual tasks perform single function
  - Tasks are independent, with well-defined interfaces
  - Higher-level programming abstraction

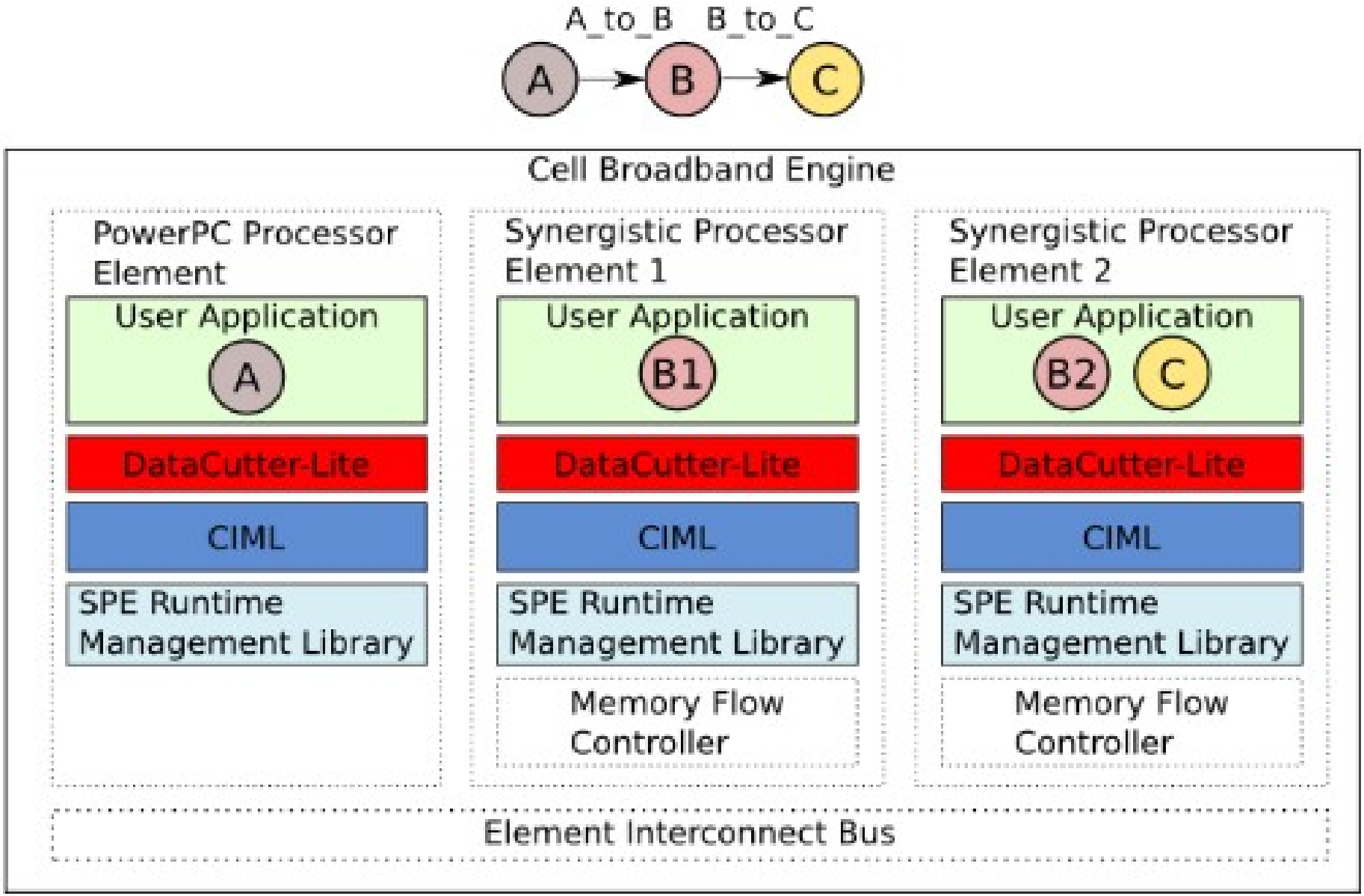
DataCutter

- DataCutter
  - Coarse-grained filter-stream framework
  - OSU/Maryland-bred component-based framework
  - Third-generation runtime uses MPI for high-bandwidth network support

DataCutter-Lite (DCL)

- Component-based, filter-stream programming framework
  - Define computation as task-graph
  - Tasks are *filters*, which are functions which compute
  - Data flows along *streams* to/from filters along pre-defined paths
  - Automatic multi-buffering of buffers
  - Automatic PPE-SPE, inter-SPE communication
- DCL is event-based
  - Arrival of stream *buffer* (a quantum of data in the application) triggers filter execution

Sample DCL Application Layout

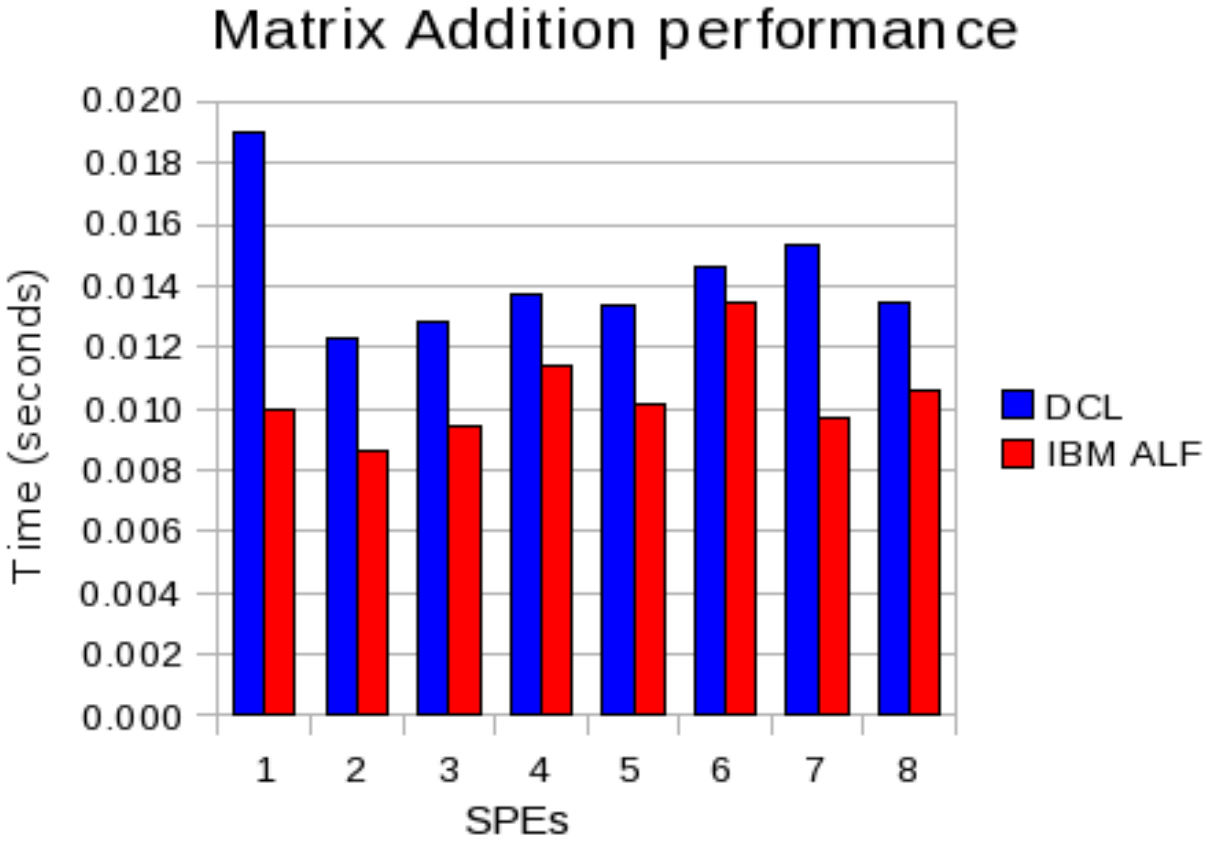


Experimental Results

- Use three applications
  - Variety of Communication-to-Computation Ratios (CCR)
- Matrix addition
  - High CCR
  - Compare with IBM's Accelerated Library Framework (ALF) example
- Image color-space transformation
  - Low CCR
  - Compare with custom-coded IBM SDK-based baseline
- Biomedical image analysis application
  - Medium CCR
  - Three-stage pipeline

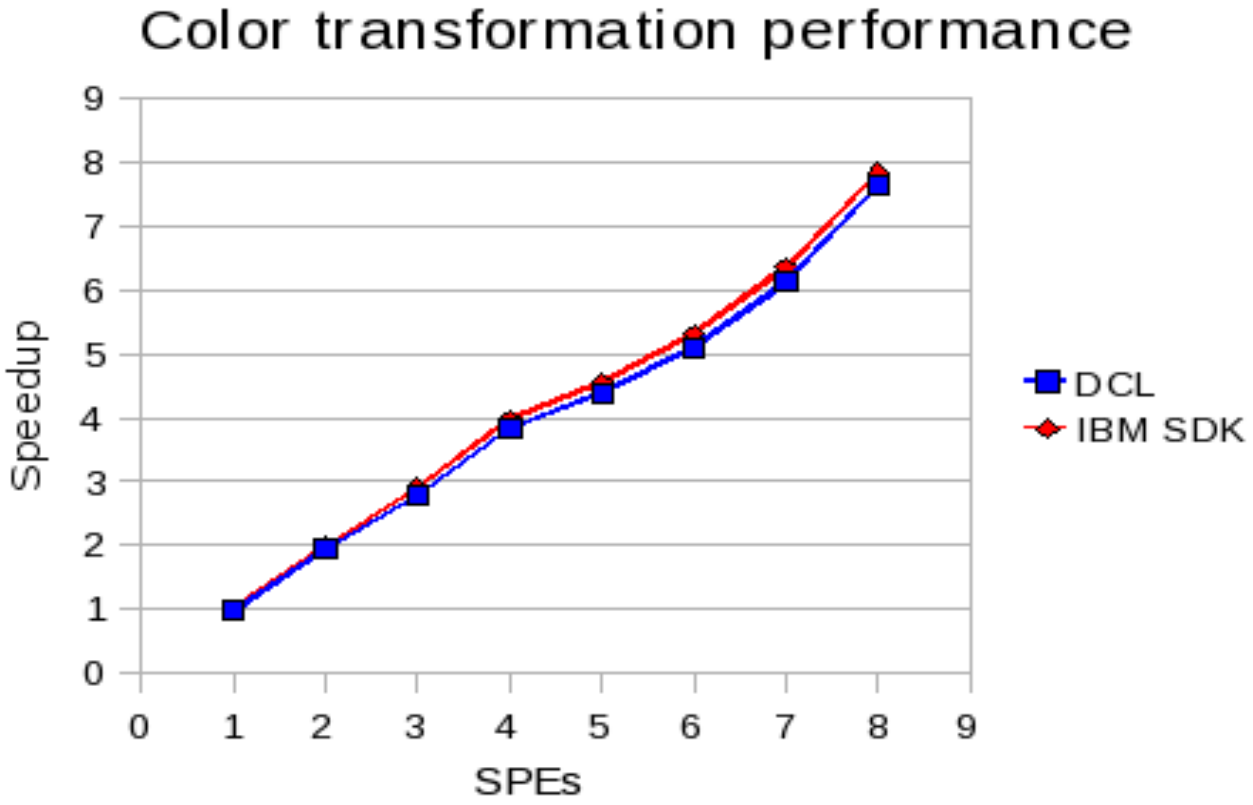
Matrix Addition Performance

- Compare against IBM ALF example
- 1024 x 512 matrix
- DCL has 8–91% longer execution time

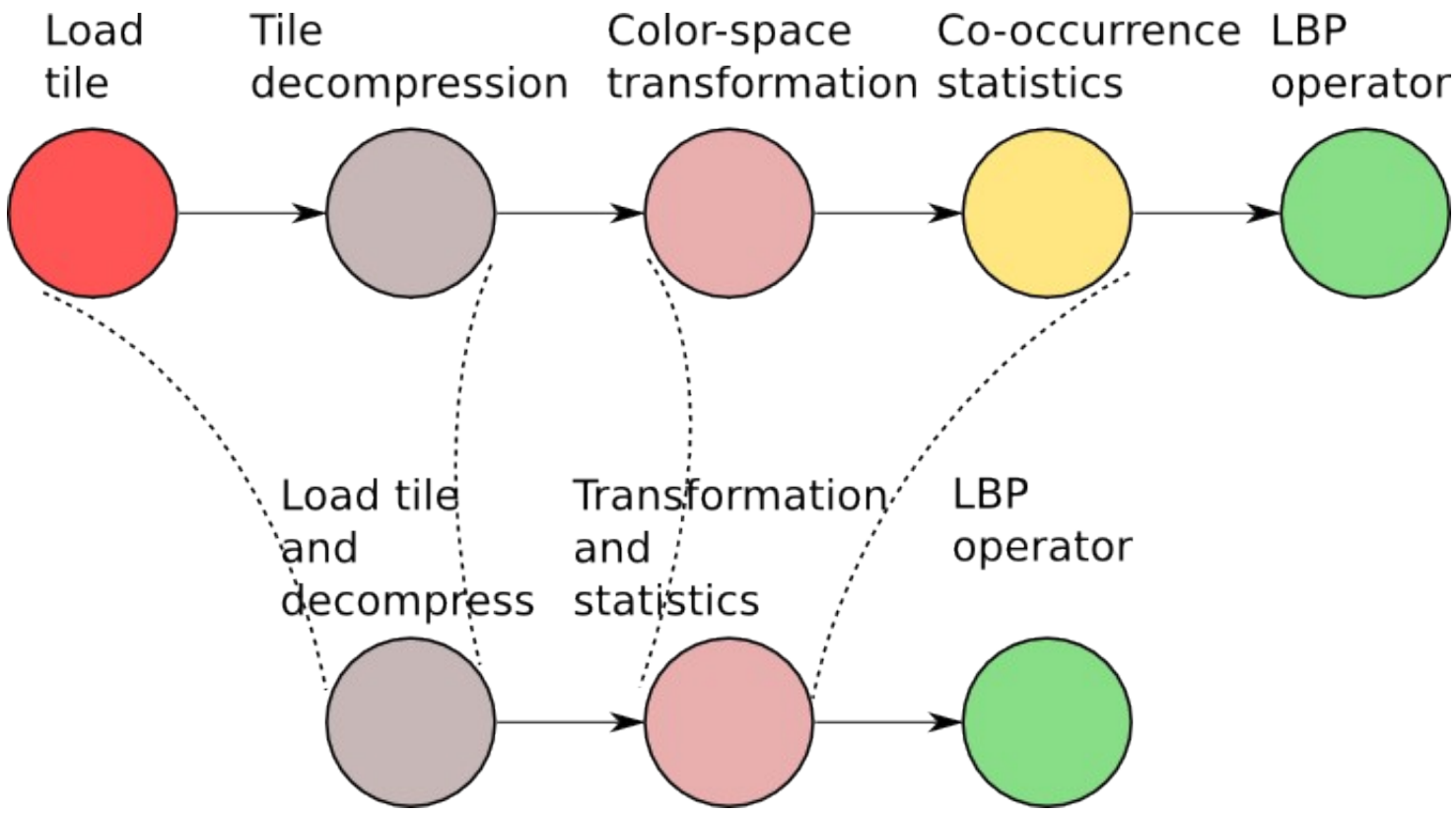


Color-Space Transform Performance

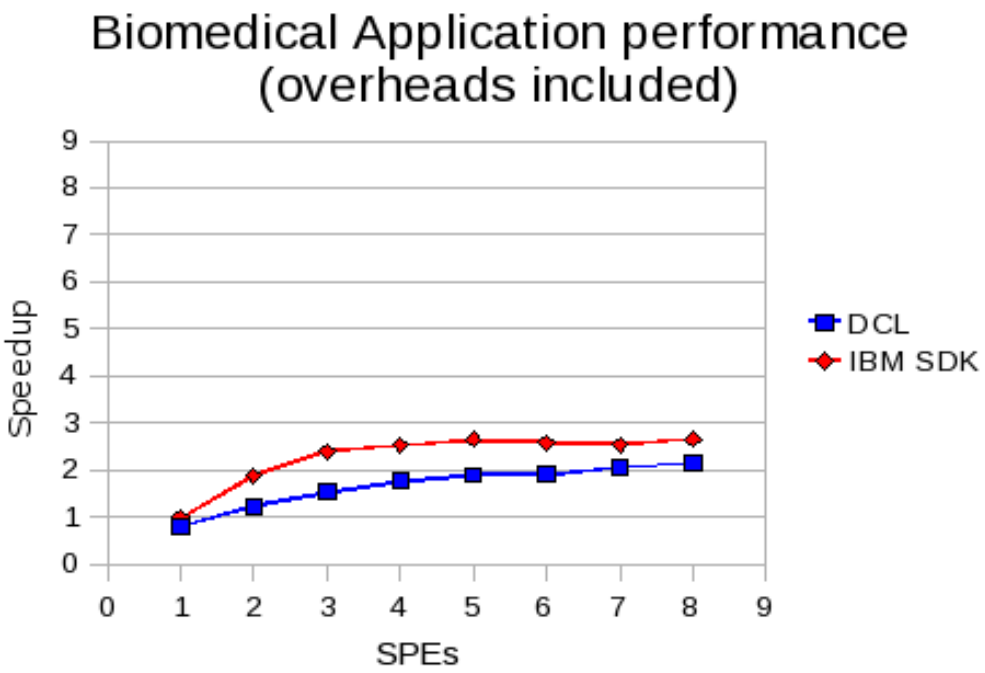
- Compare against custom IBM SDK version
- 32 1Kx1K image tiles
- DCL has 2-4% longer execution time

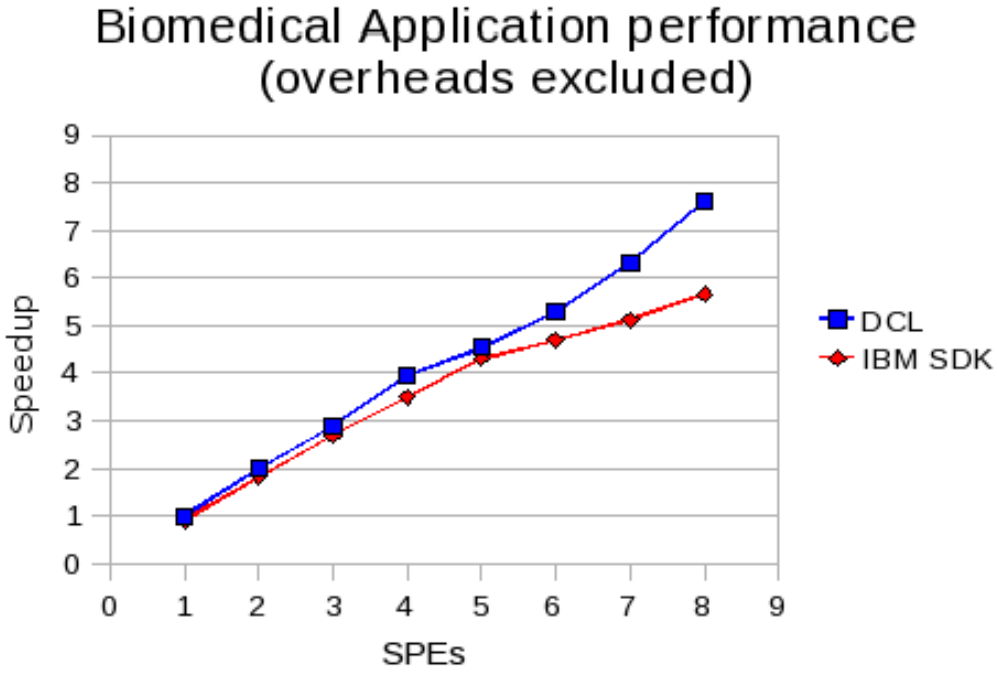


Biomedical Application Filter Layout



Biomedical Application Performance

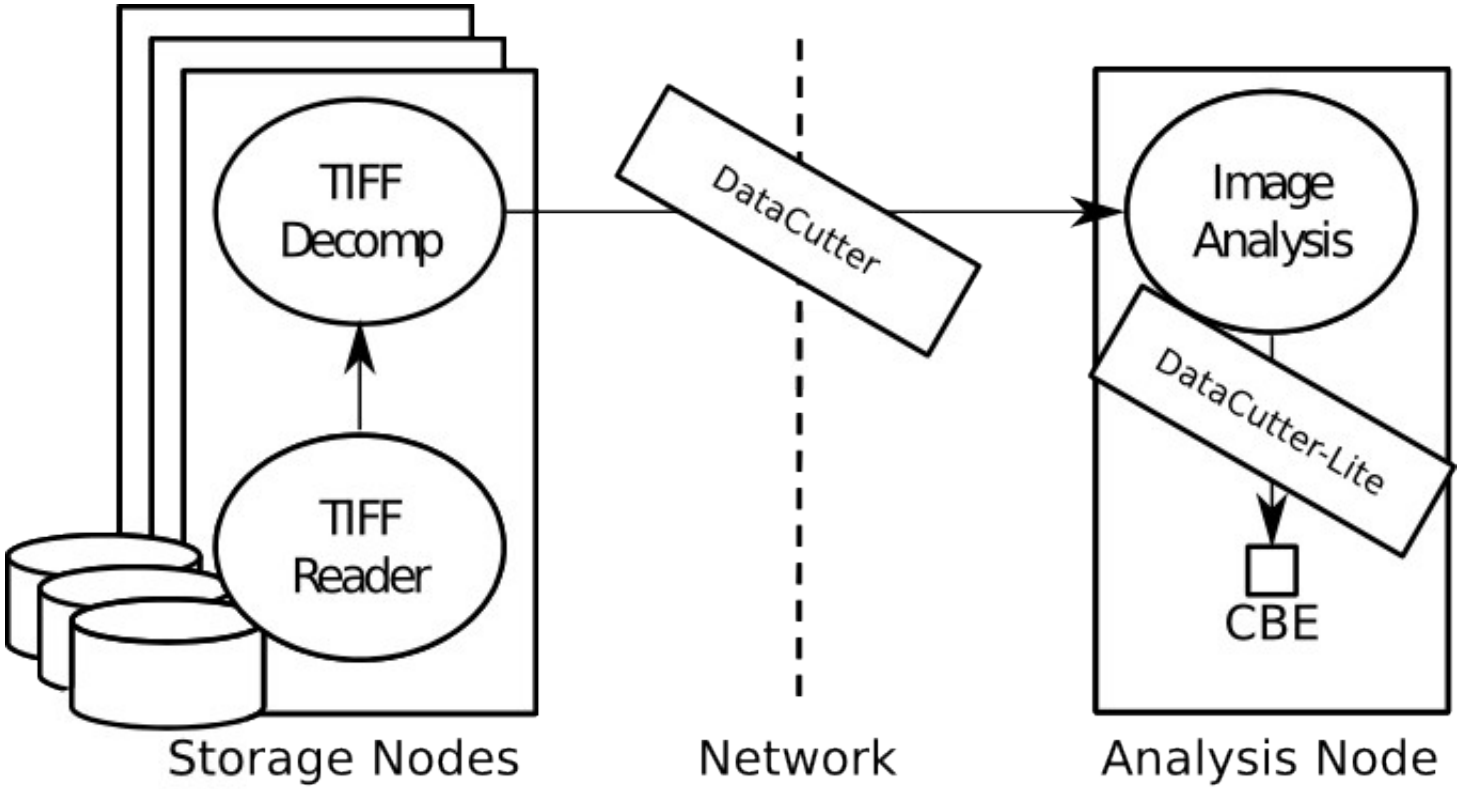




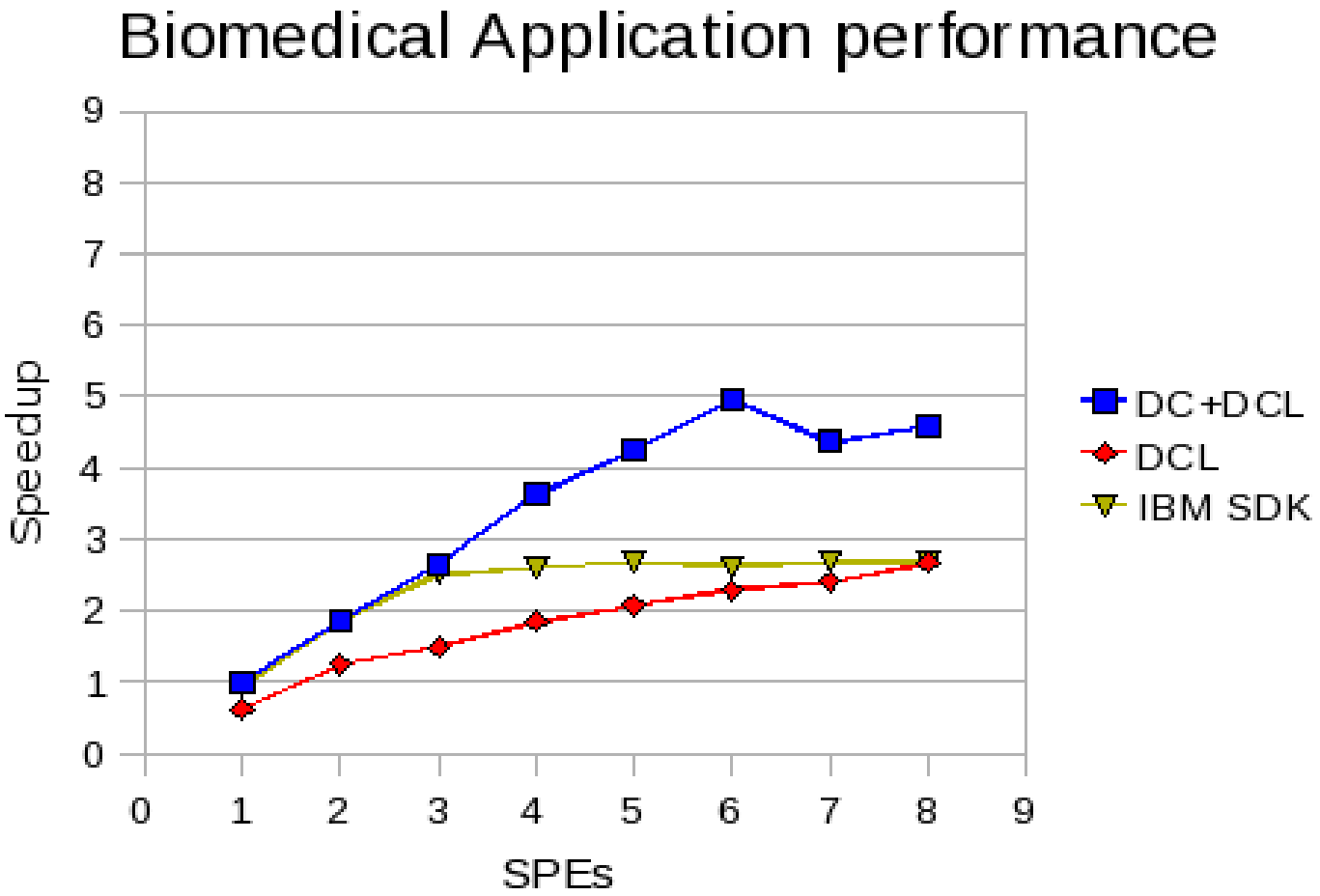
- Compared against custom IBM SDK version
- 32 1Kx1K image tiles
- Overheads included: DCL takes 23-57% longer
- Overheads excluded: SDK takes 5-26% longer

Mixed Granularity DataCutter Example

- DataCutter for coarse-grained parallelism
- DCL for fine-grained parallelism



Biomedical Application Performance (2)



- 1024 1Kx1K image tiles
- DC+DCL has up 42% shorter execution time

Conclusions Future Work

- Contributions
  - Two-sided communication library (CIML)
  - Filter-stream programming framework and runtime engine (DataCutter-Lite)
- Conclusions
  - CIML and DCL give good performance with easier programming than raw IBM SDK
- Future work
  - Extend fine-grained filter-stream framework to CMP, GPU
  - Automate trial-and-error fine-tuning
  - Simplify placement/sizing of filter instances with performance modeling

Related Work

- MPI-like
  - MPI u-tasks – IBM Research
  - Cell Messaging Layer (CML) - LANL
- Block-based
  - BlockLib
  - Sequoia - Stanford
  - Charm++ - UIUC
  - Accelerated Library Framework (ALF) – IBM SDK
- Source compilers
  - CellSs - BSC
- Streaming frameworks
  - StreamIt – MIT

DCL Code Examples

- PPE Code
  - main()
  - setup_application()
  - filter function
- SPE Code
  - filter function

```
// Omitted: Set up Matrices A, B, pointers, a_ptr,
// b_ptr, constants
int main(int argc, char ** argv) {
 init_dcl();

 for (i = 0; i < NUM_ROWS; i++) {
  DCLBuffer * buffer =
   create_buffer("raw_data",
   BUF_SIZE);

  append_array(buffer, a_ptr,
   NUM_COLS * sizeof(float));
  append_array(buffer, b_ptr,
   NUM_COLS * sizeof(float));

  stream_write(buffer);
  // Omitted: increment pointers a_ptr, b_ptr
 }
 finish_dcl();
 return 0;
}
```

DCL Code Examples

- PPE Code
  - main()
  - setup_application()
  - filter function
- SPE Code
  - filter function

```
// PPE setup and filter code
// Called by init_dcl()
void setup_application(Placement * p) {
 Filter * console = get_console(p);
 Filter * fadded = place_ppu_filter(p,
       "added_data");
 Filter * fadder = place_filter(p, 0, "add_values");

 Stream * sraw = add_stream(p, "raw_data");
 add_source(p, sraw, console);
 add_sink(p, sraw, fadder);

 Stream * sadded = add_stream(p,
      "added_matrix");
 add_source(p, sadded, fadder);
 add_sink(p, sadded, fadded);
}
```

DCL Code Examples

- PPE Code
  - main()
  - setup_application()
  - filter function
- SPE Code
  - filter function

```
// When receving a buffer from SPE
void added_data(DCLBuffer * buffer) {
  // Omitted: Deal with added matrix data
}

EVENT_PROVIDE1(added_data);
```

DCL Code Examples

- PPE Code
  - main()
  - setup_application()
  - filter function
- SPE Code
  - filter function

```
// Omitted: Set up constants
void add_values(DCLBuffer * buffer) {
 DCLBuffer * out_buffer = create_buffer(
      "added_matrix", BUF_SIZE);

 float * a = get_float_data_pointer(buffer);
 increment_extract_pointer(buffer,
      num_values * sizeof(float));
 float * b = get_float_data_pointer(buffer);
 float * c = get_float_data_pointer(out_buffer);

 for (i = 0; i < NUM_COLS; i++)
  c[i] = a[i] + b[i];

 stream_write(out_buffer);
}

EVENT_PROVIDE1(add_values);
```