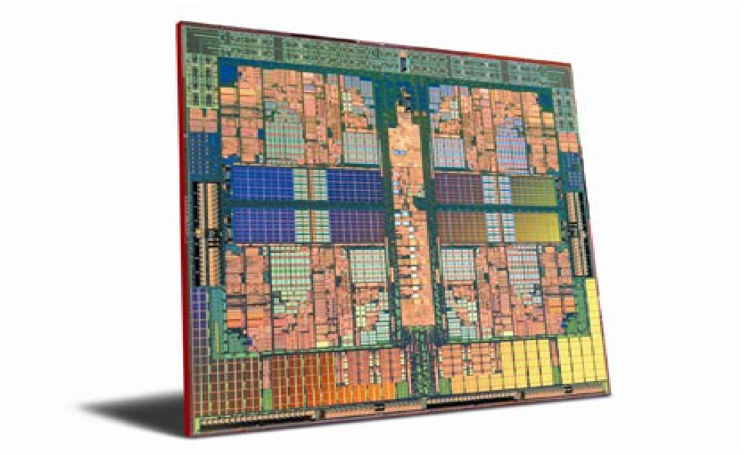
IEEE 14th International Conference on High Performance Computing And Communication

June 2012

The Multiscale Hybrid Programming Model

A Flexible Parallelization Methodology



Nader KHAMMASSI
Jean-Christophe Le Lann
Jean-Philippe Diguet
Alexandre Skrzyniarz

» **Structured Parallel Programming**

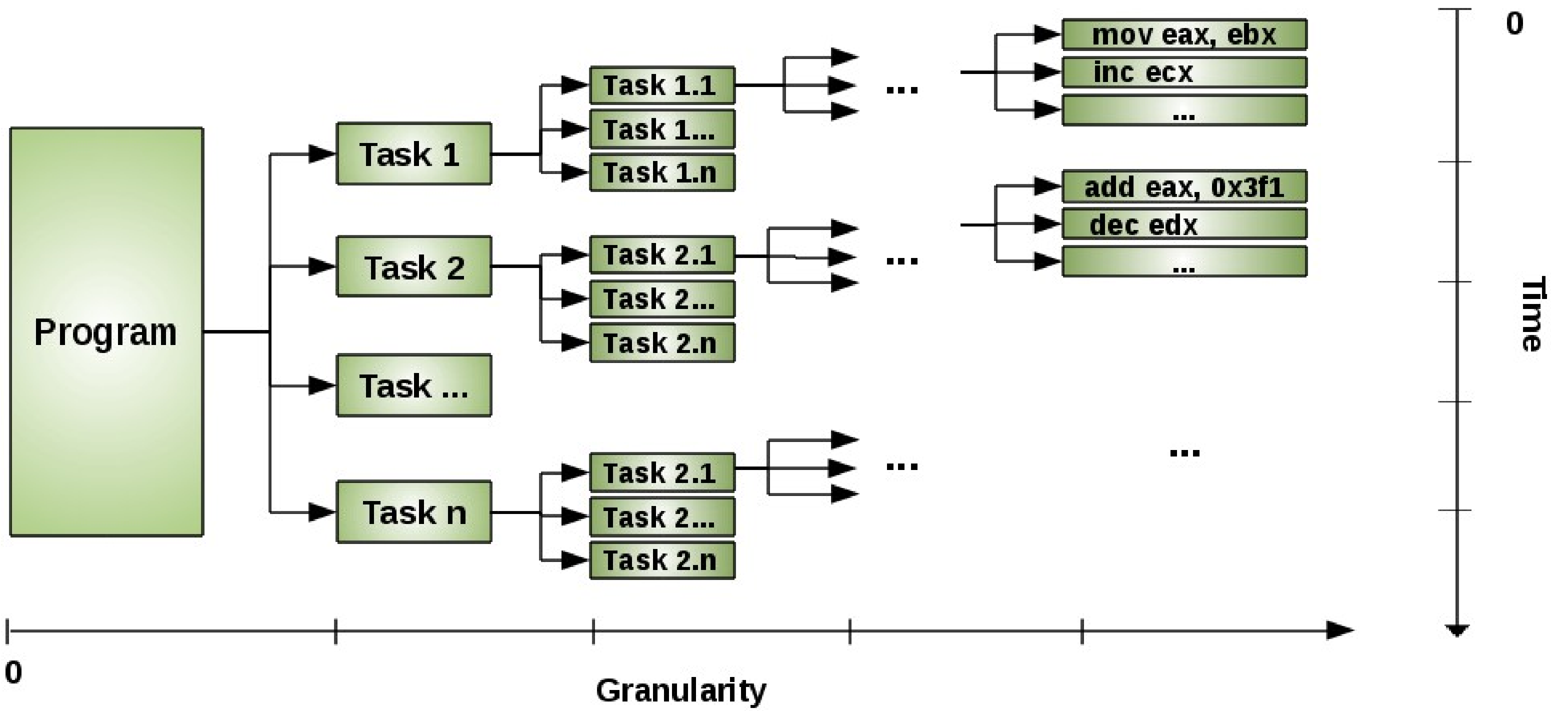
» Structured Parallel Programming With Skeletons

- High-Level approach based on a collection of recurrent deterministic execution patterns.
- Execution Patterns ↔ Algorithmic Skeletons ↔ Parallel Constructs
- Skeletons abstracts program description and hide low-levels multithreading details and many complexities inherent in parallel programming.
- Skeletons automates many parallel programming paradigm-related routines such communication, synchronization and data partitionning...
- Skeletons are reusable.
- Skeletons provides enough hardware abstraction to let the programmer focus on algorithm instead of architecture.

- **Task-Based Parallelization Methodology**

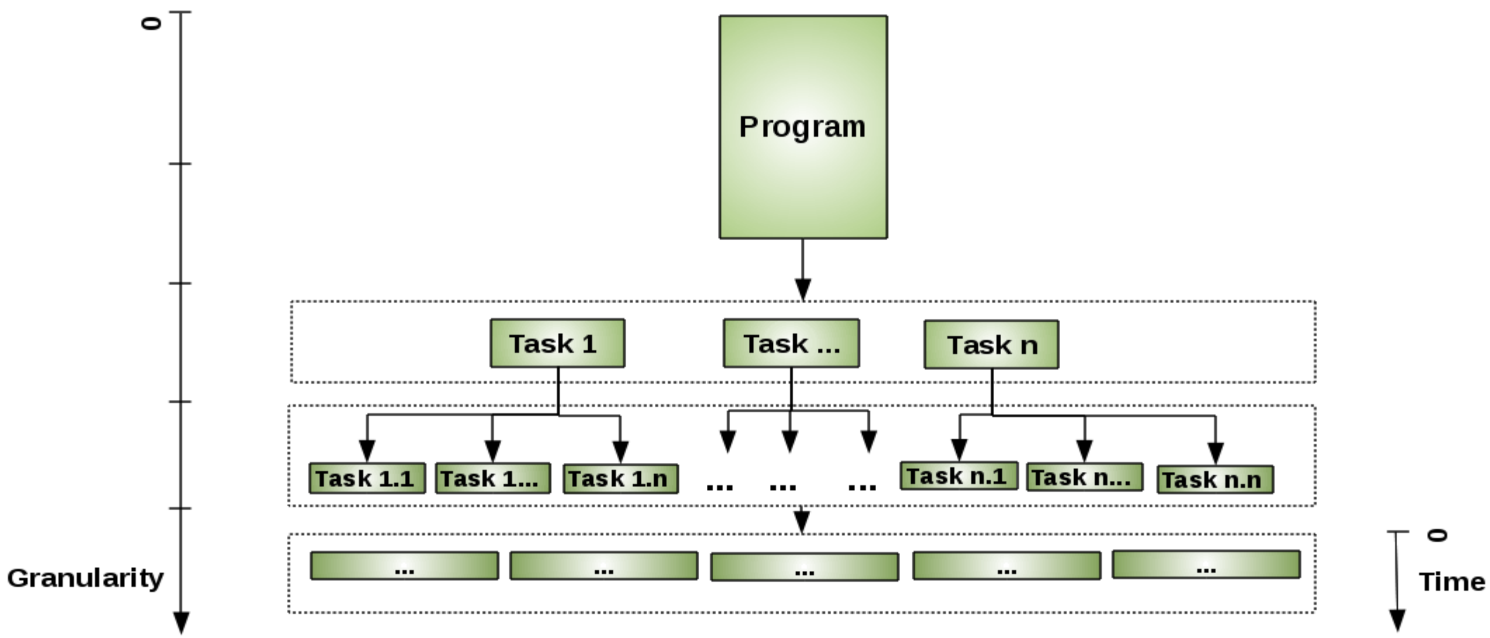
» The First Step : Program Decomposition Into Tasks

- The sequential program can be decomposed into coarse-grain tasks.
- These tasks can be decomposed in turn into finer grain tasks... etc
- Programmer can control task granularity to extract the maximum amount of available parallelism.



Parallelism Specification

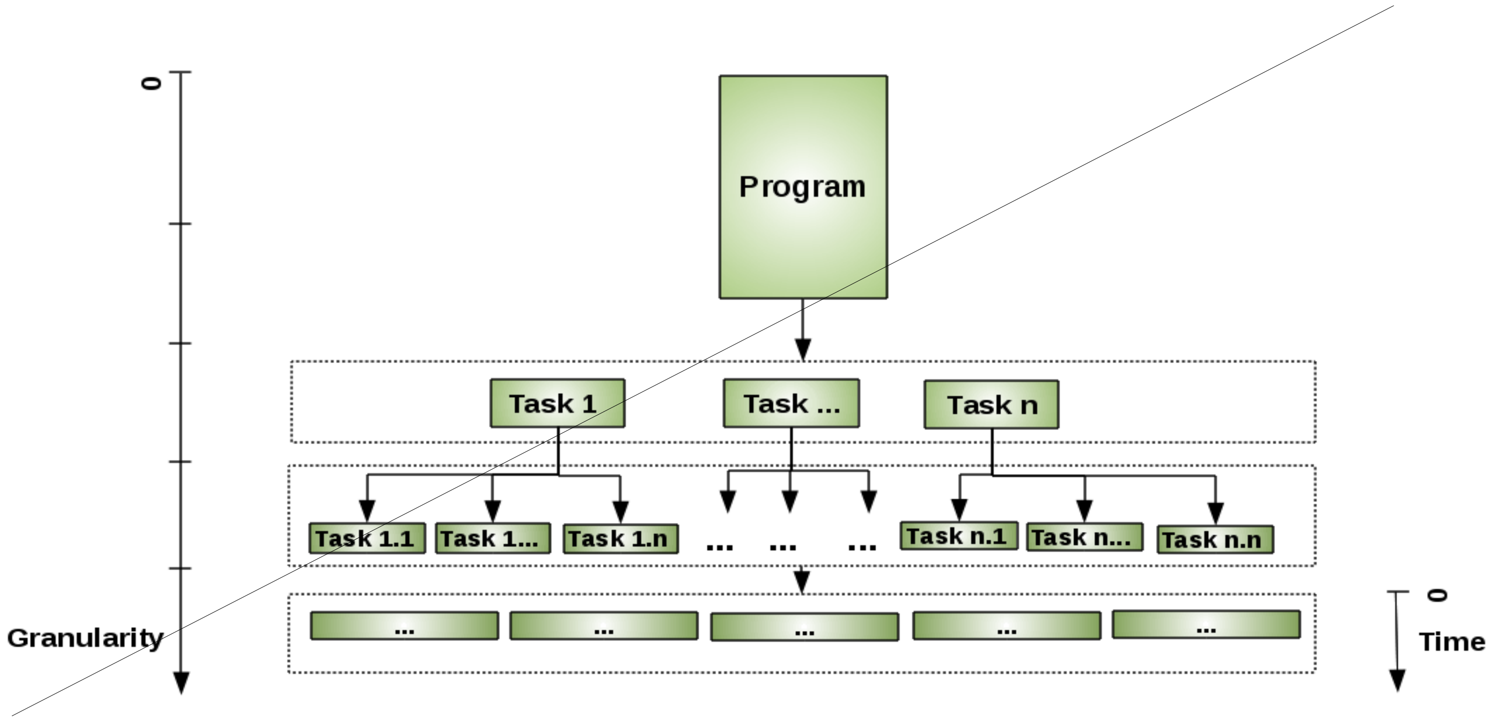
- **The ideal case** : All tasks can be executed simultaneously !



"Ideal Case : Perfect Parallel Execution"

Parallelism Specification

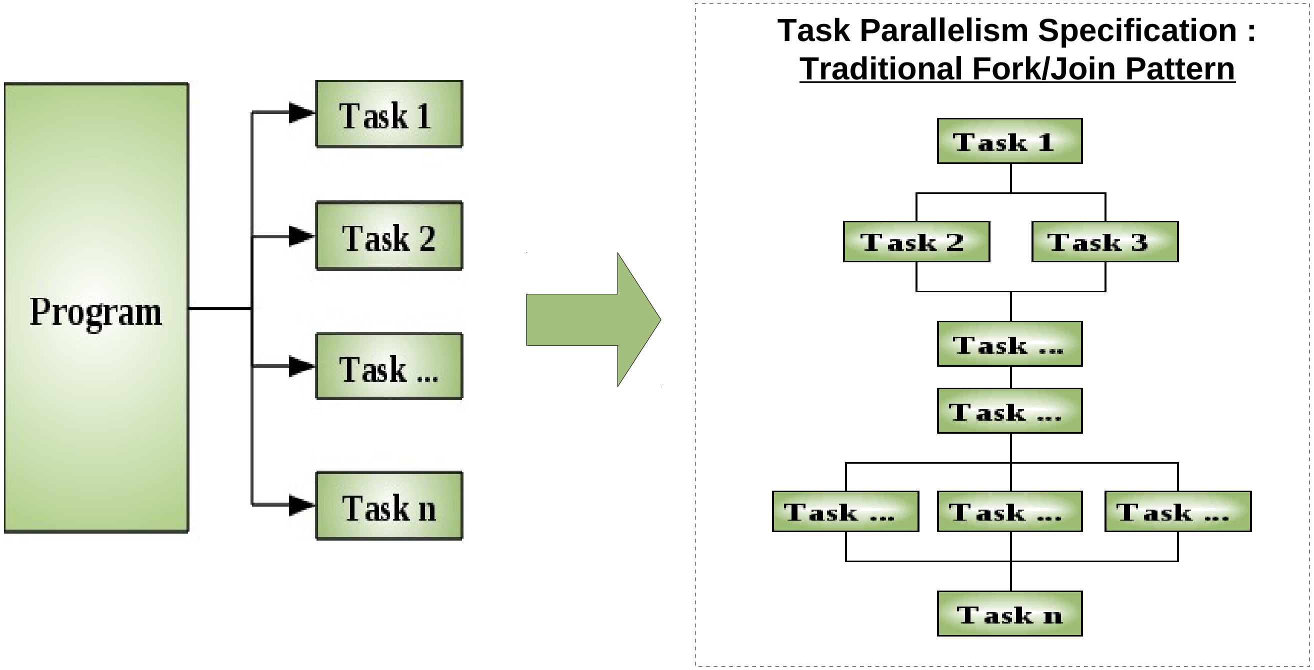
- **The ideal case** : All tasks can be executed simultaneously !
- Unfortunately, programs are **“more-or-less” parallelizable** → contains a **varying amount of parallelism** depending on algorithmic constraints and task-data dependencies.



“Ideal Case : Perfect Parallel Execution”

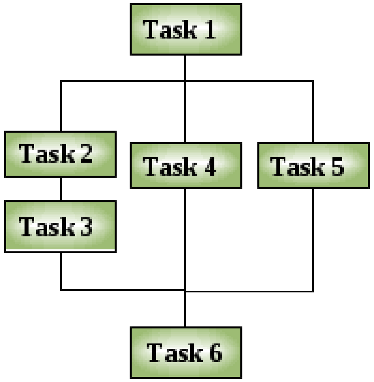
Parallelism Specification : Traditional Fork/Join Pattern

- Depending on the available parallelism, tasks can be executed either **simultaneously or sequentially**
- This Hybrid Execution can be specified using the traditional Fork/Join execution pattern.



Parallelism Specification : Fork/Join Limitations

- However, **parallelism can be available at several levels of granularity** !
- Simple Fork/Join execution pattern specify parallelism at a single level of granularity.
- However, parallelism can be available at several different levels of granularity.



"2 Levels Task Parallelism Specification"

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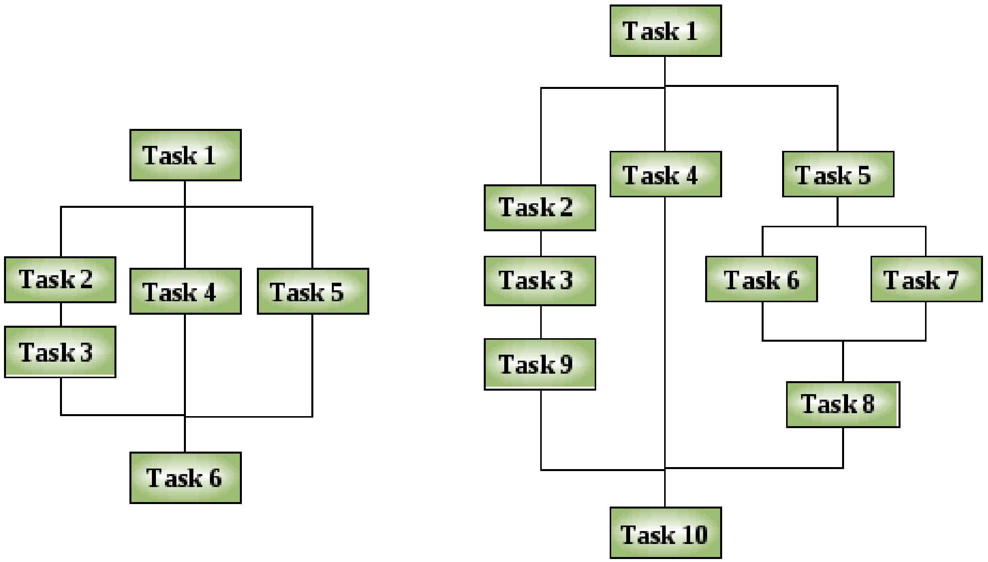

"2 Levels Task Parallelism Specification"

"3 Levels Task Parallelism Specification"

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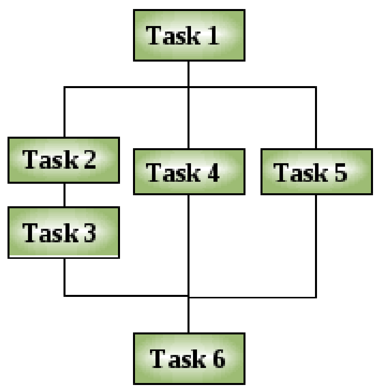

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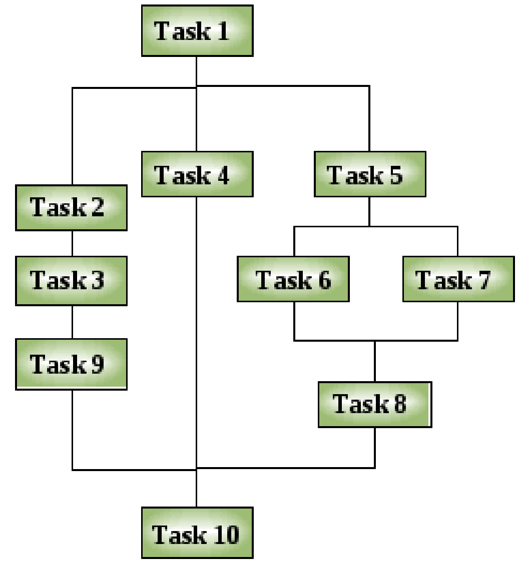

"3 Levels Task Parallelism Specification"

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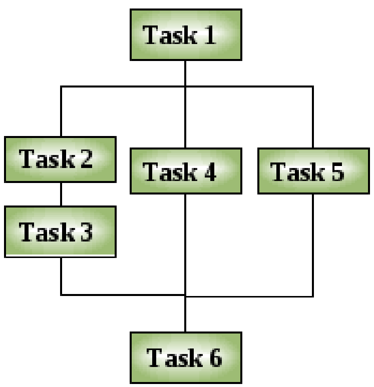
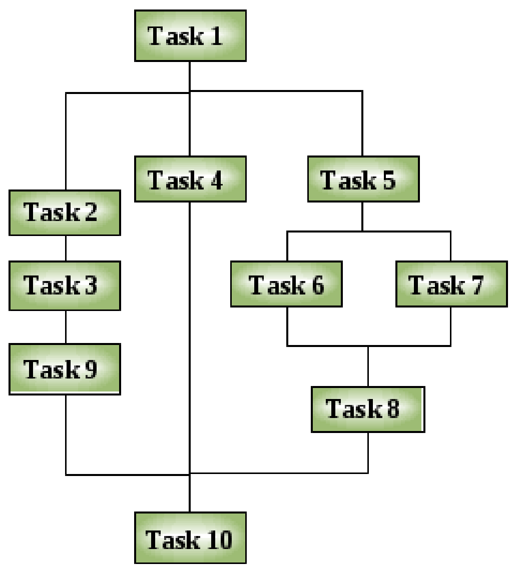
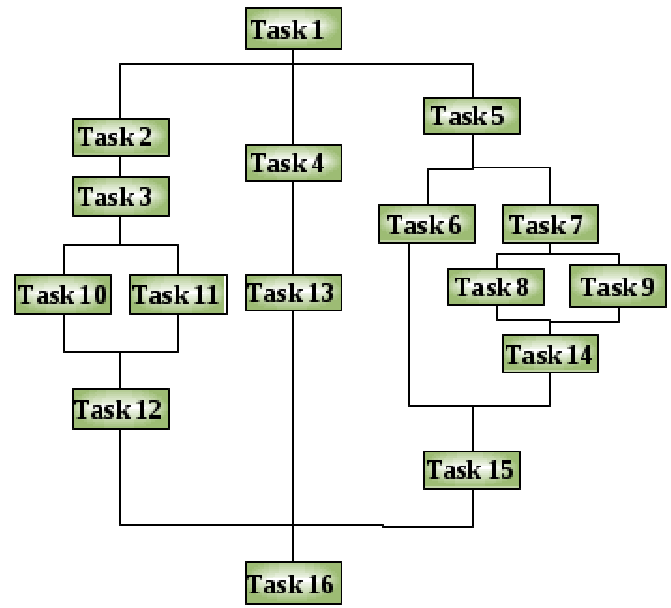


"2 Levels Task Parallelism Specification"



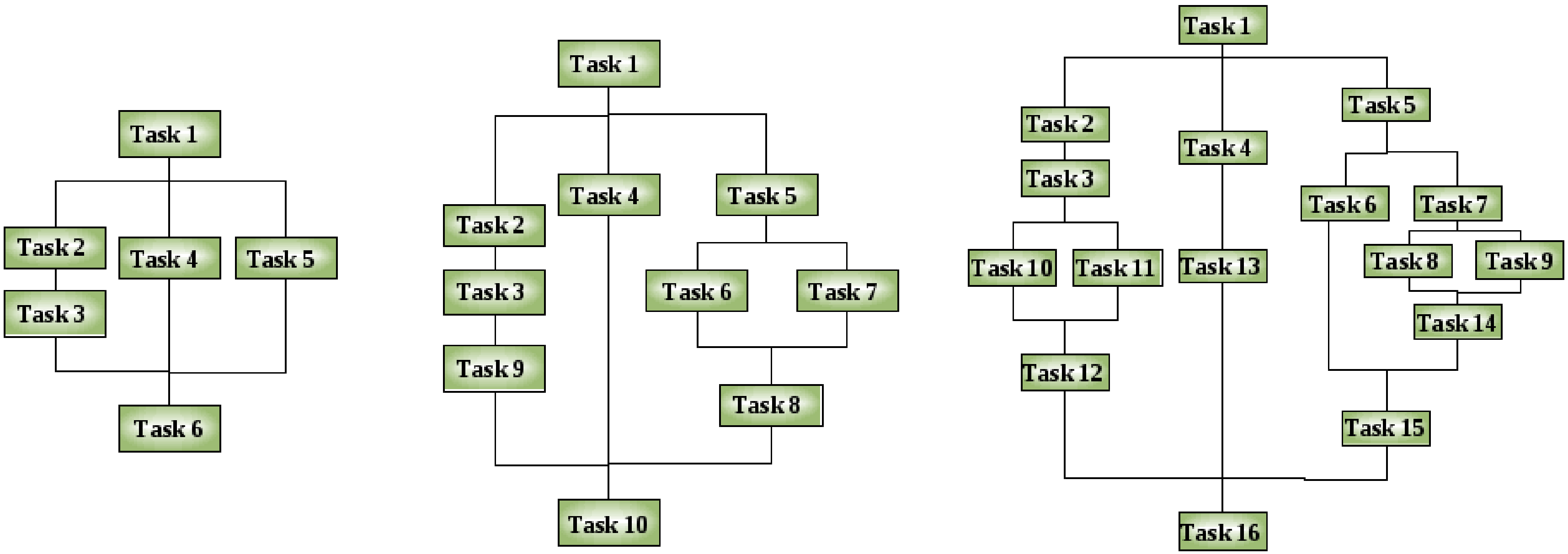
"3 Levels Task Parallelism Specification"



"4 Levels Task Parallelism Specification"

Parallelism Specification : The Hierarchical Task Graph

- The ***Hierarchical Task Graph*** is composed from hierarchical Fork/Join constructs.
- The HTG can specify task parallelism at many levels of granularity.



"Hierarchical/Nested Task Parallelism Specification "

Parallelism Specification : The Hierarchical Task Graph

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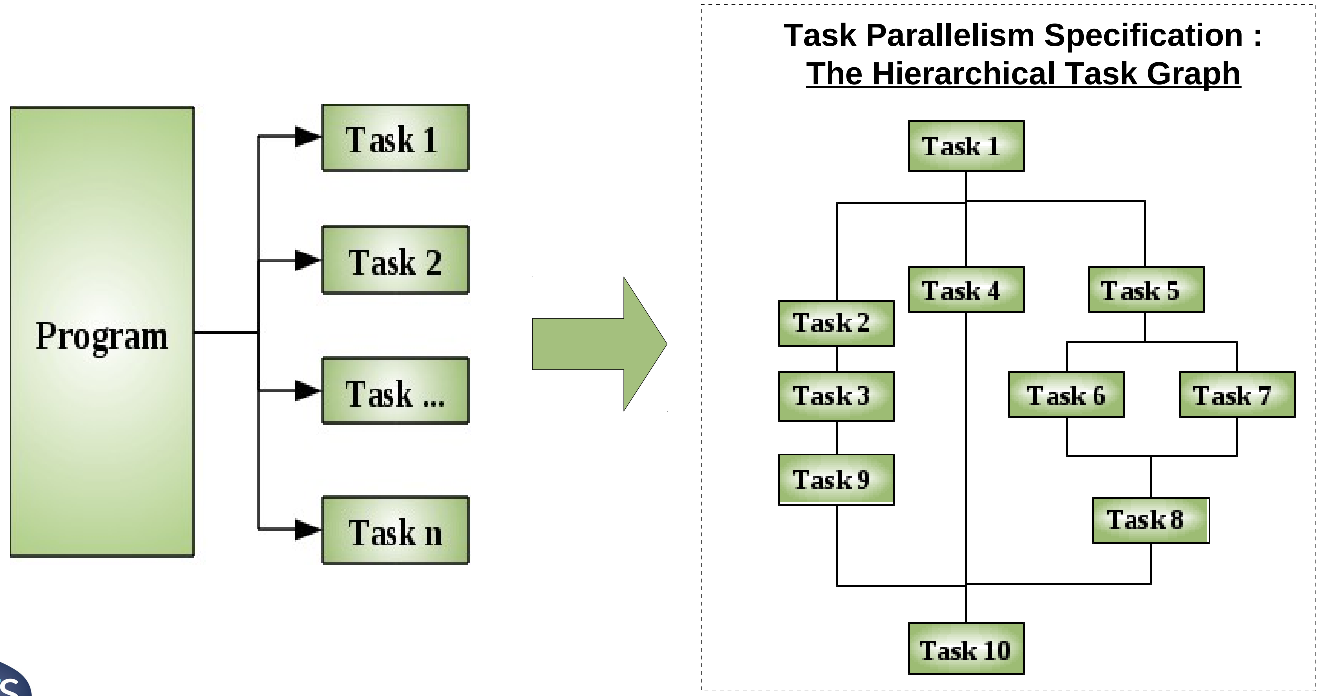
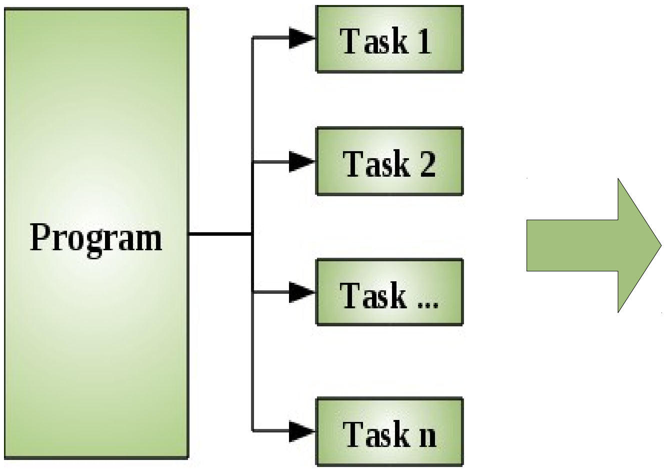
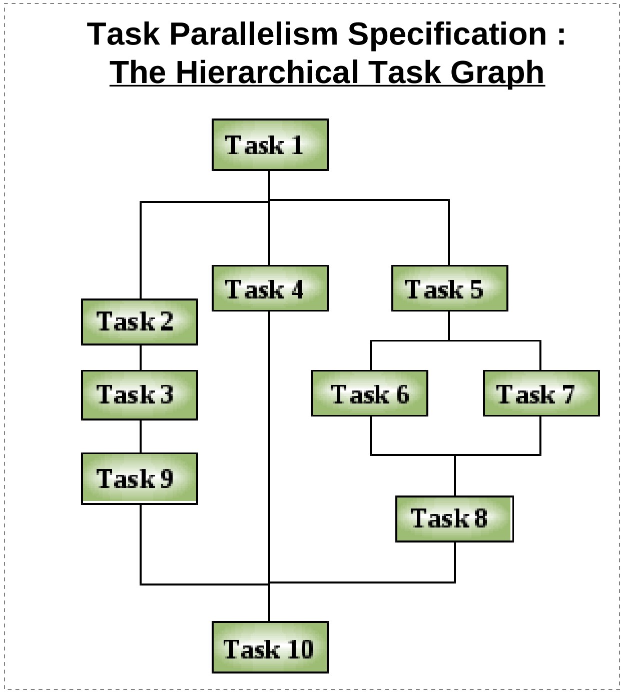


» Parallelism Specification : The Hierarchical Task Graph

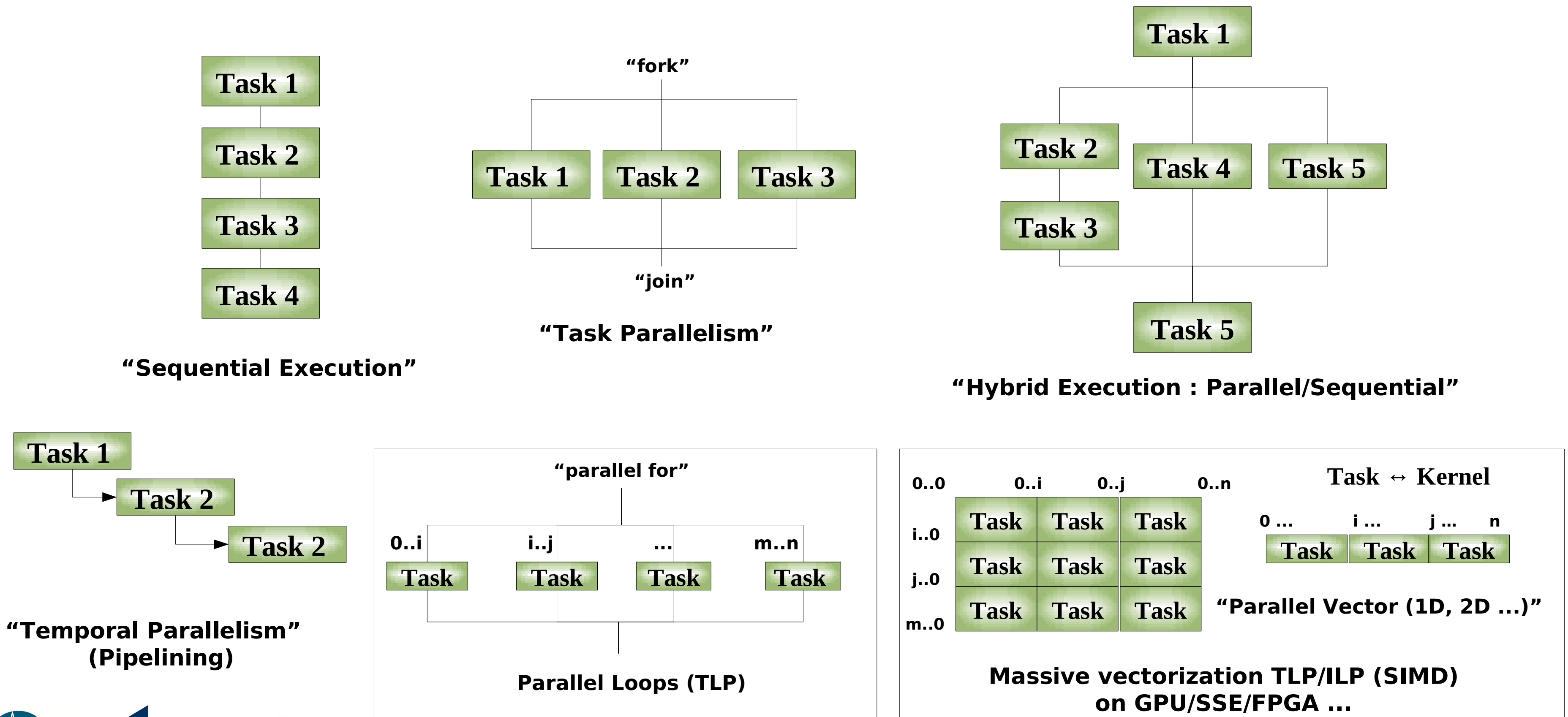
- The ***Hierarchical Task Graph*** is composed from hierarchical Fork/Join constructs.
- The HTG can specify task parallelism at many levels of granularity.
- However, a program may exhibit different types of parallelism and not only fork/join-based task parallelism.





Parallelism Specification : Parallelism Types

- A program may exhibit different types of parallelism and not only fork/join-based task parallelism.

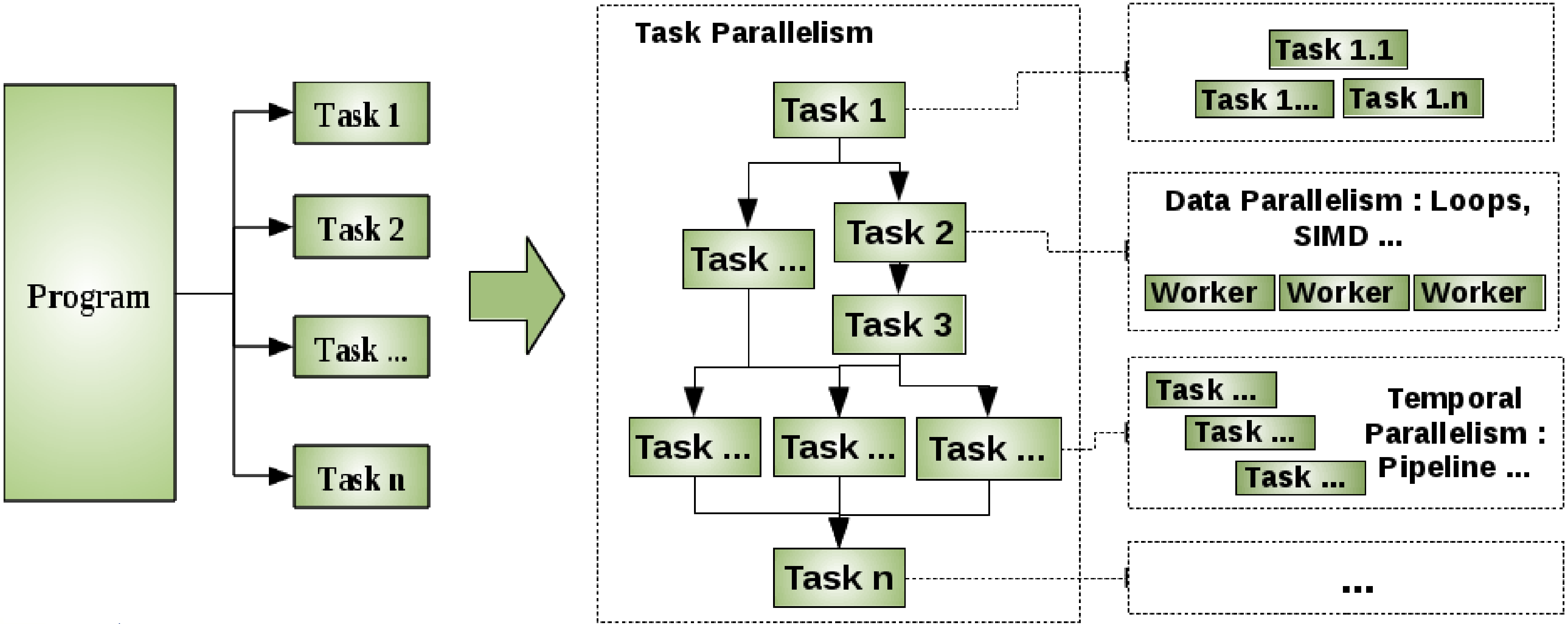


"Data Parallelism"

» HTGG: The Hierarchical Task Group Graph

Parallelism Specification : The HTGG

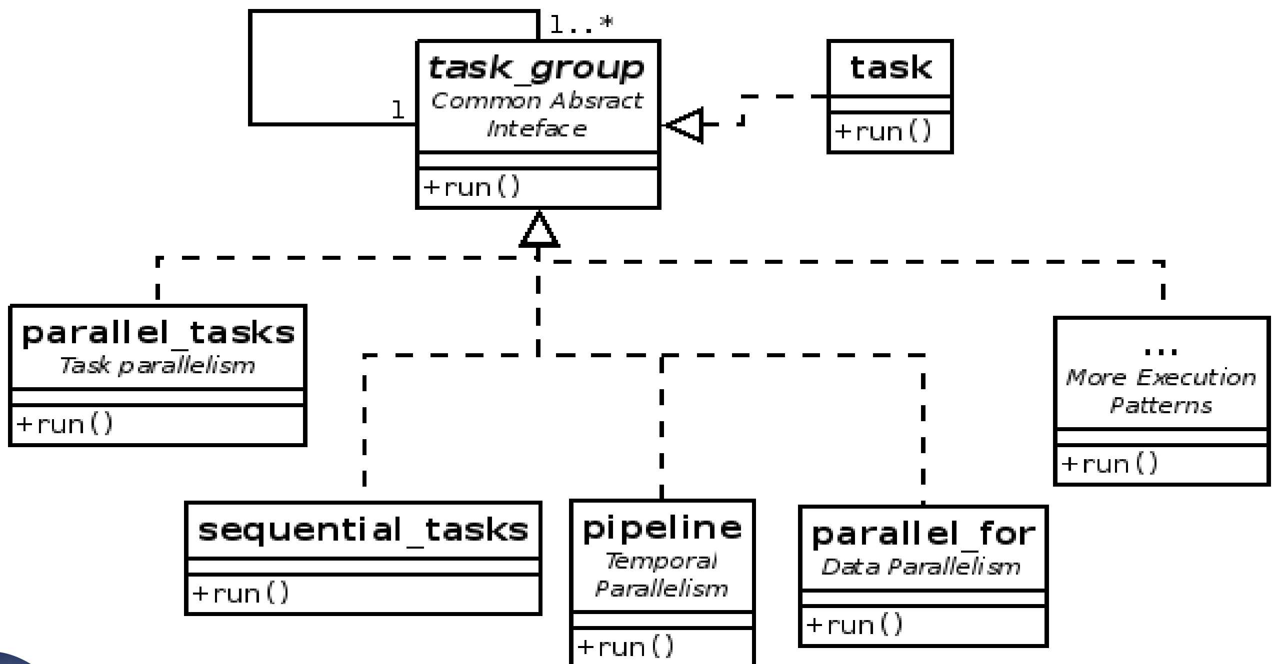
- The **Hierarchical Task Group Graph (HTGG)** uses Task Group instead of simple task to accommodate execution patterns heterogeneity.
- The HTGG is a rich program intermediate representation which specify many different types of parallelism at different levels of granularity.



"The Hierarchical Task Group Graph" (HTGG)

Parallelism Specification : The Task Group Interface

- The "task_group" is a common abstract interface which can be implemented by an extendable collection of execution patterns specifying different types of parallelism.
- "task_group" interface accommodate the HTGG heterogeneity and allow specification of different execution configurations into a single homogeneous construct.



» **Example : Parallelization of a simplified Multimedia Application**

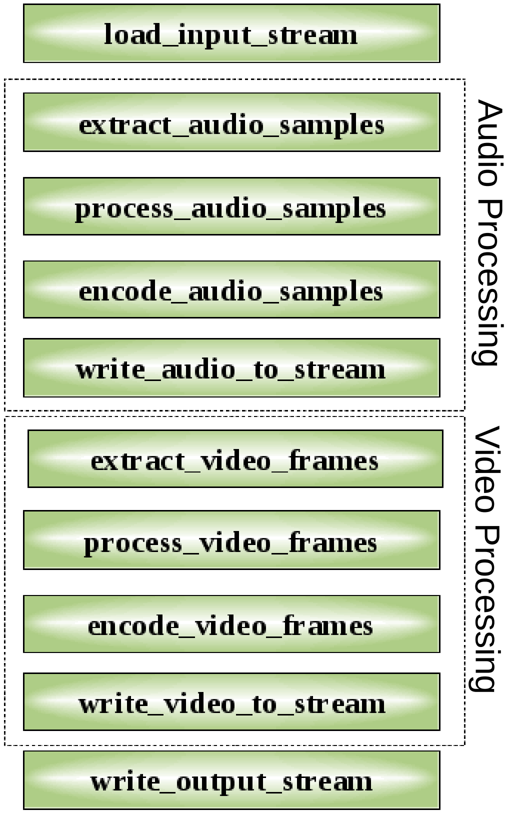
Example

- **Parallelization of a simplified multimedia application**

- An example of a sequential multimedia application
  - Read an input stream
  - Process and encode **audio** bitstream
  - Process and encode **video** bitstream
  - Write common output stream

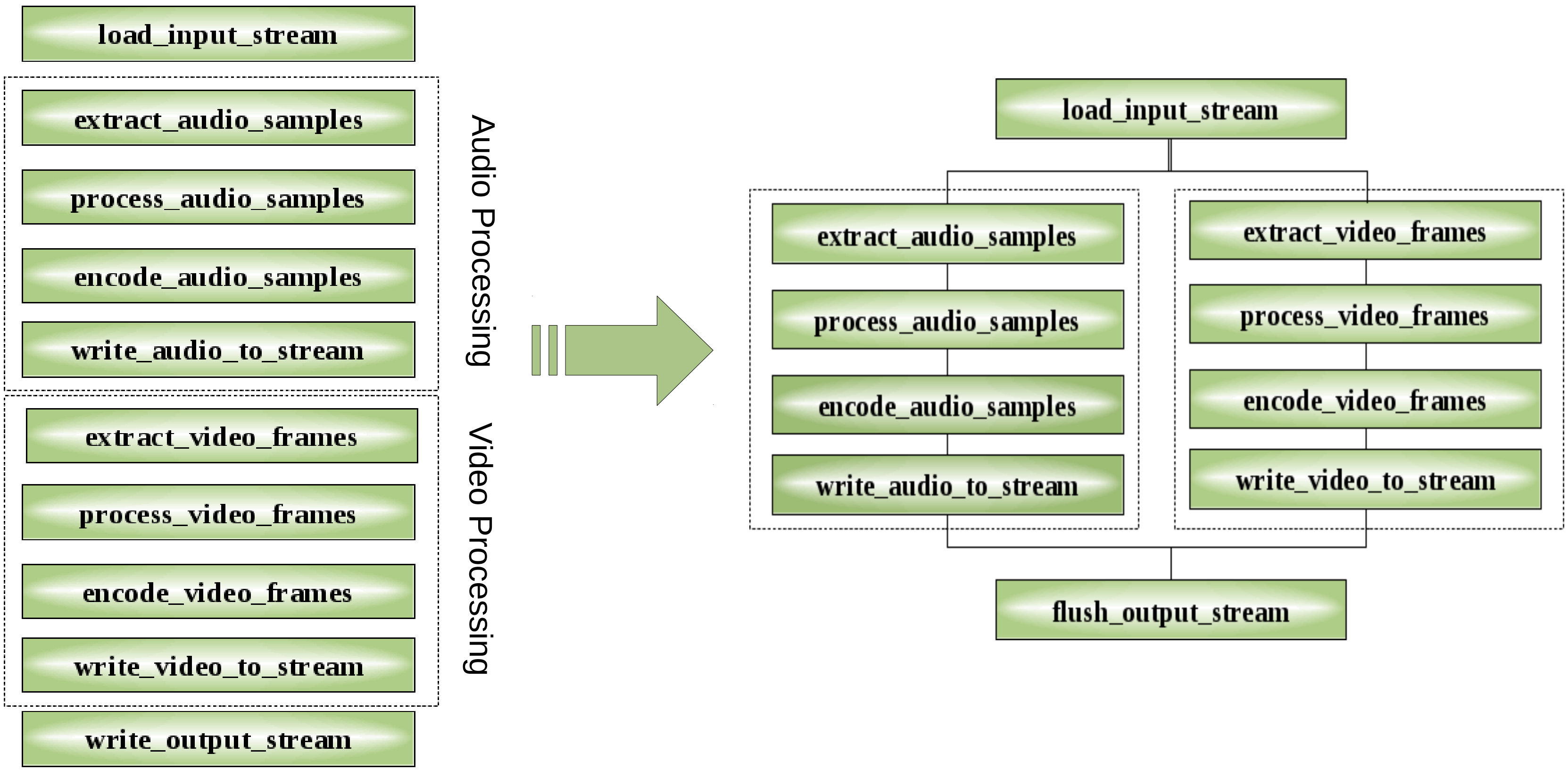
- Firstly, the application is decomposed into a set of sequential tasks

- How to parallelize it ?



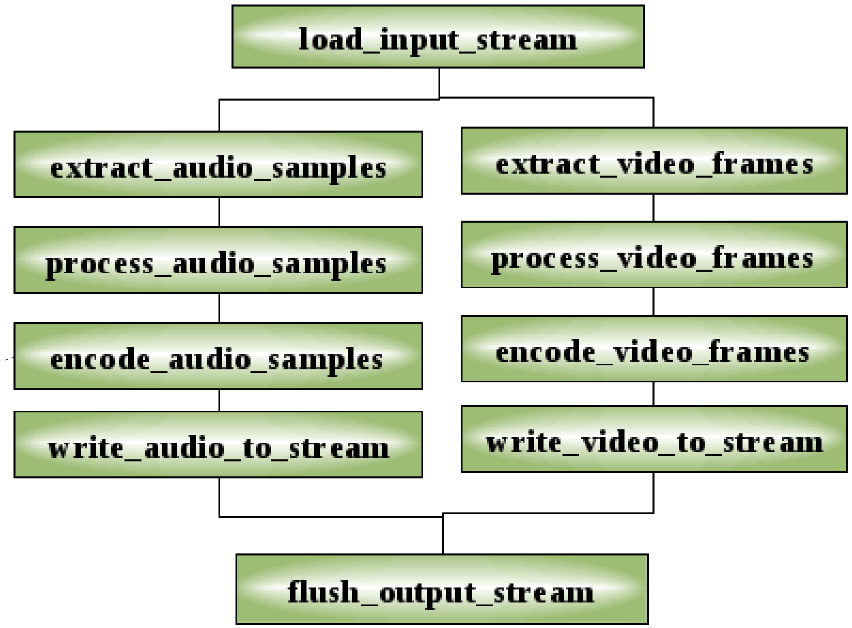
Example

- Coarse-Grain Task Parallelism Specification

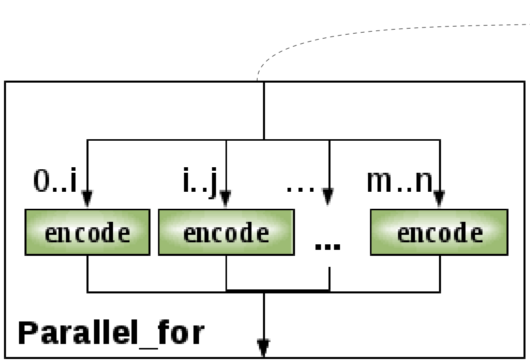


» Example

- Finer Grain Data Parallelism Expression



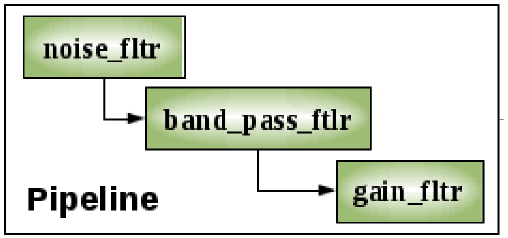
« Main Task Parallelism »



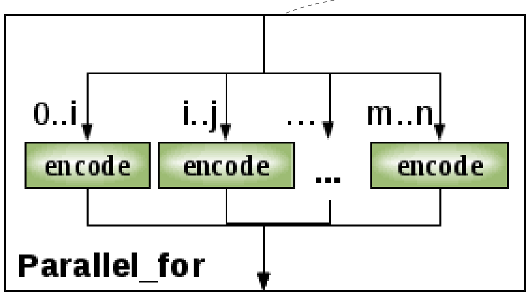
« Data Parallelism »

Example

- Temporal Parallelism Specification



« Temporal Parallelism »



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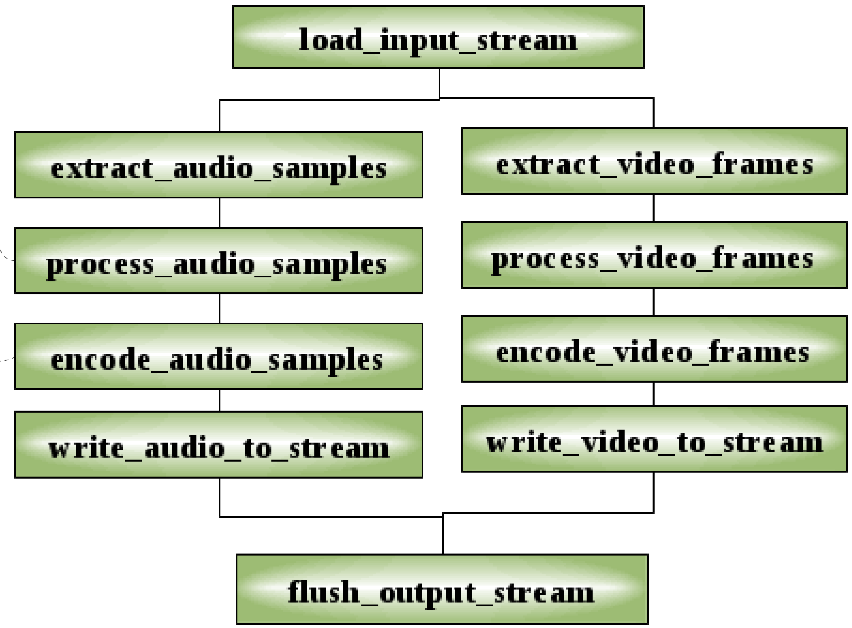
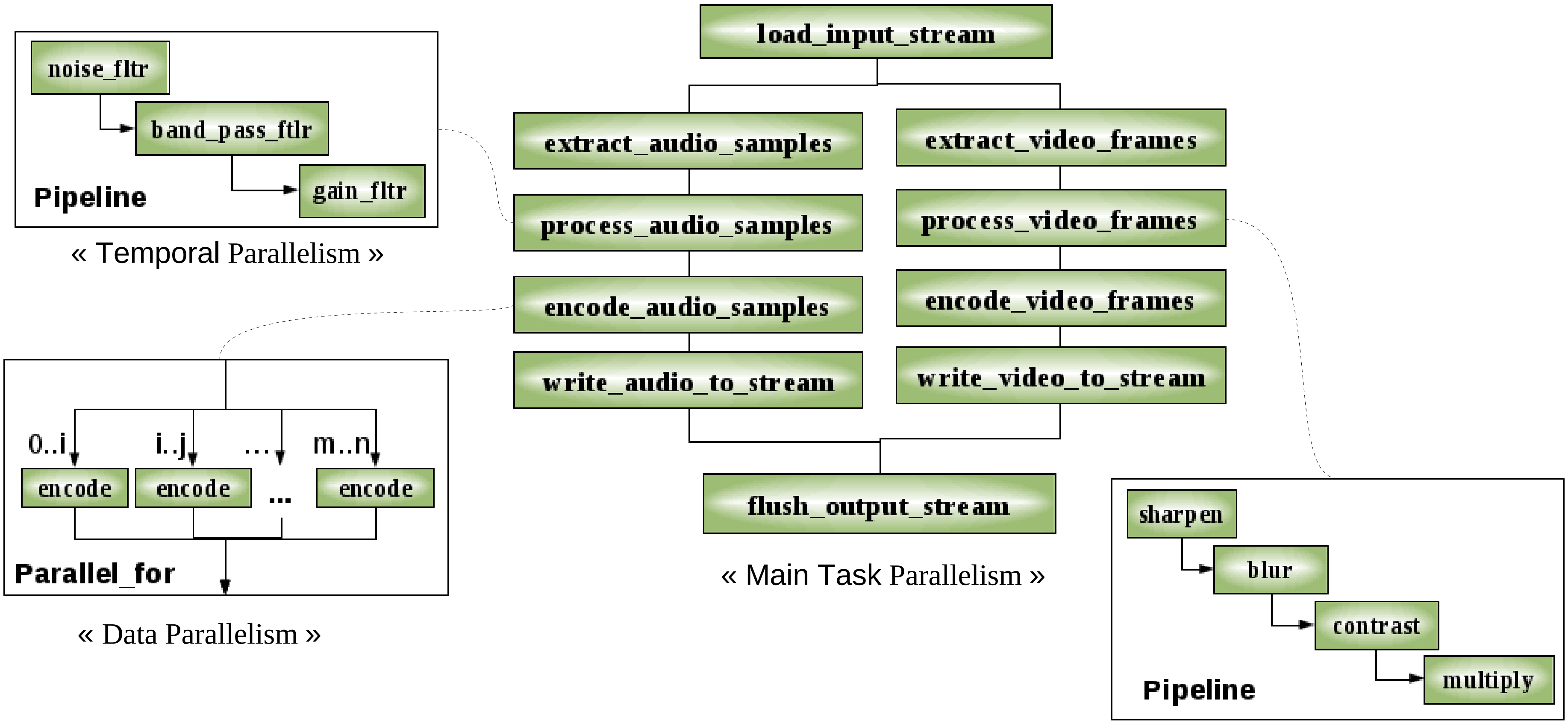


« Main Task Parallelism »

Example

- More Parallelism ...



« Temporal Parallelism »

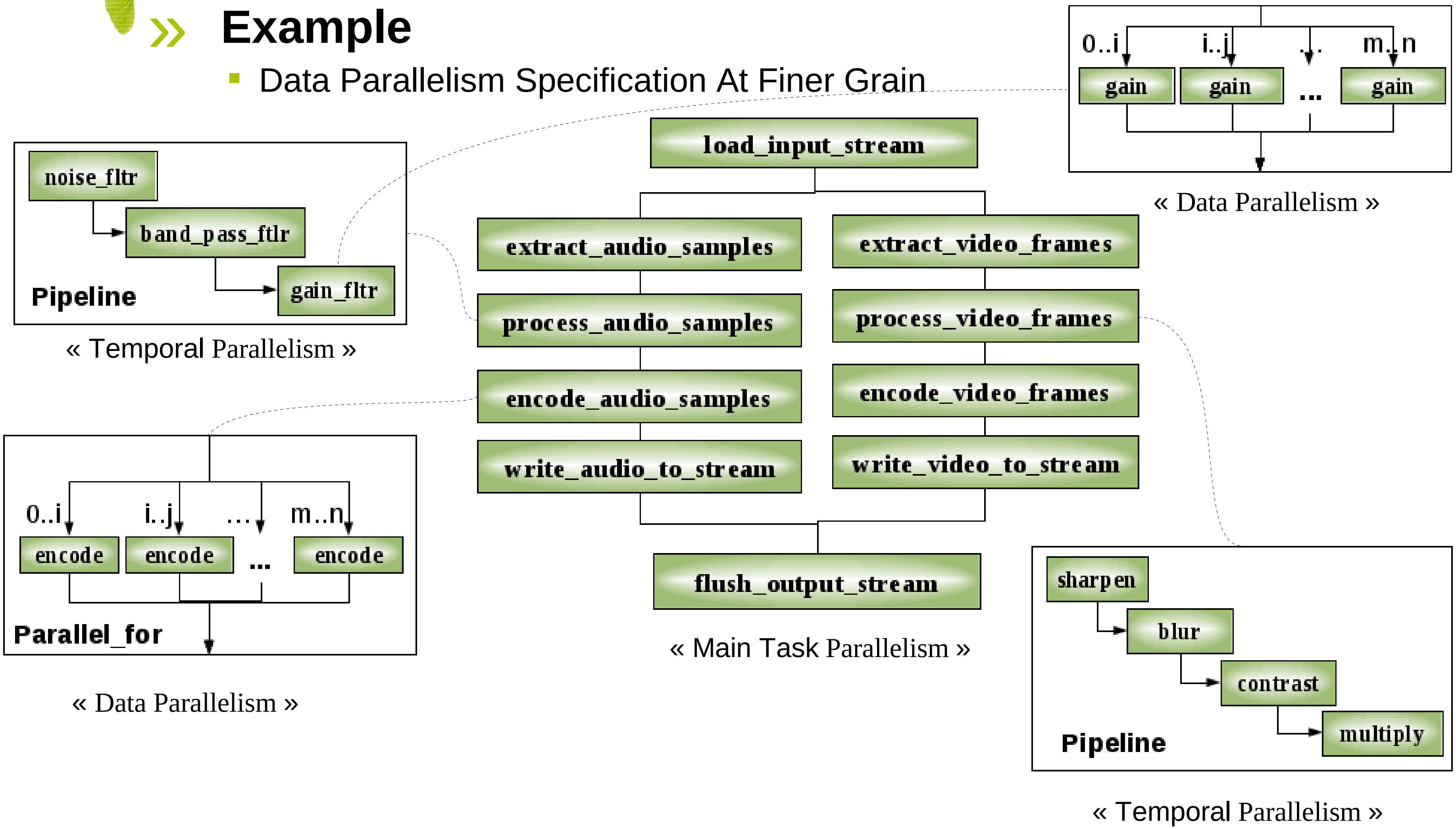
« Main Task Parallelism »

« Data Parallelism »

« Temporal Parallelism »

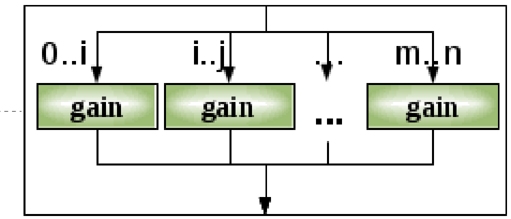
Example

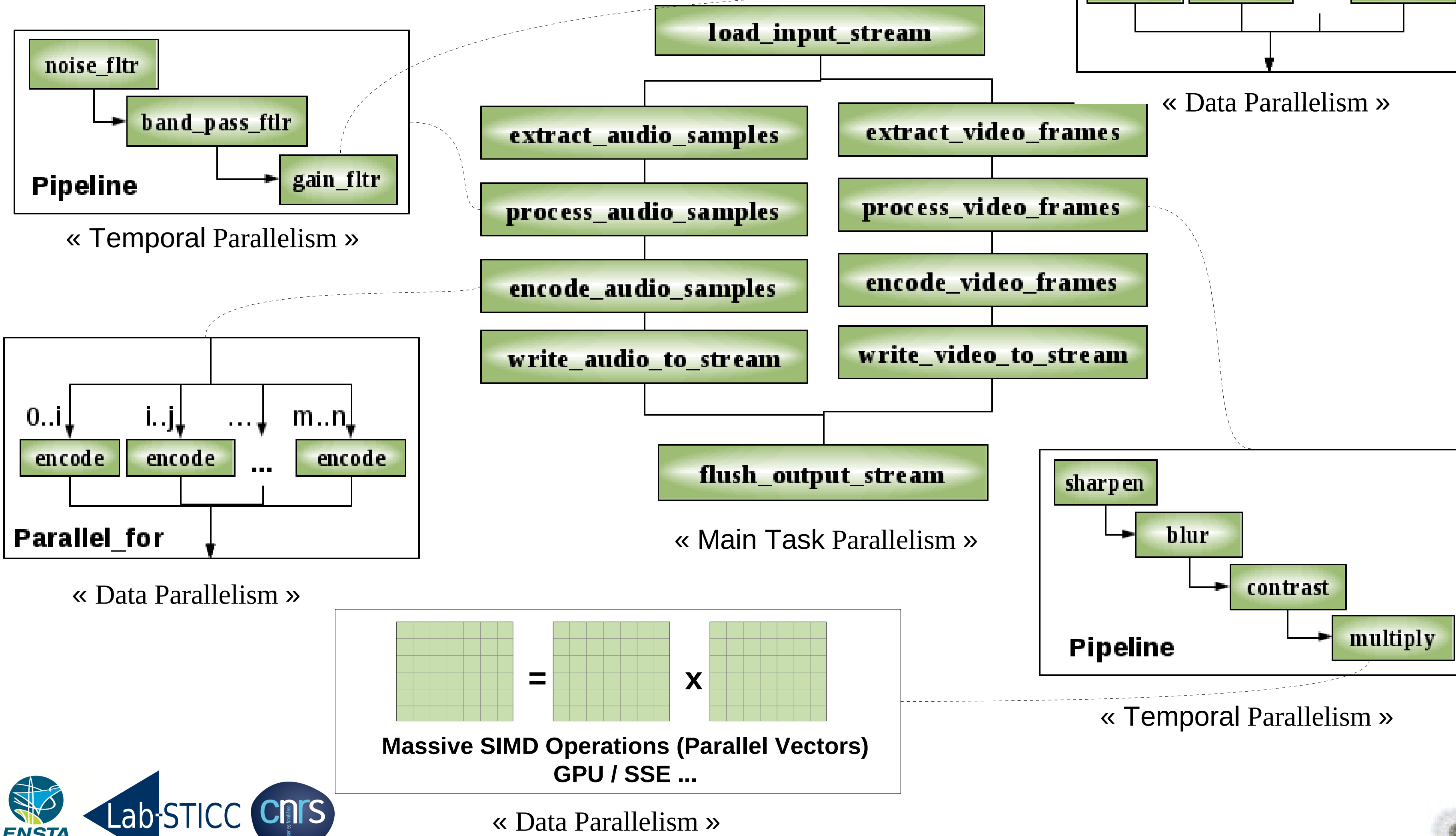
- Data Parallelism Specification At Finer Grain



Example

- More Data Parallelism At Finer Grain





» Parallelism Expression From Graphical to Code
The XPU Framework

Parallelism Expression : Graphical → Code

- The HTGG has an intuitive graphical representation.
- But, How to translate such “complex” construct into simple and compact code ?

» Parallelism Expression : The XPU Framework

- XPU : X Processing Unit (Target Heterogeneous Multicore Architectures)
- XPU Framework is a pure C++ implementation of our programming model.
  - → Easy to learn (Traditional C++ without any extensions).
  - → Easily portable to many systems.
- Exploit C++ meta-programming capabilities to provide a friendly programming interface allowing easy expression of parallelism and producing efficient code.
- XPU is designed for high productivity and programmability.
- XPU automates many parallel programming paradigms-related routines such as tasks synchronization and shared memory management.
- XPU has an Intelligent Run-Time System (IRS) which optimize dynamically program execution on the underlying architecture : Cache-aware Task Scheduling, Scalable Data Parationning.

The XPU Programming Interface : Task Definition

- Task definition in XPU is designed to promote the reuse of sequential code through a flexible programming interface.
- XPU Task support an extendable list of piece of code, including **functions**, **class methods** or **lambda expression**.
- Task implementations can be extended to support **remote functions call** on distributed systems.

» The XPU Programming Interface : Task Definition

```
int load_input_stream(char * in_stream);
int extract_audio_samples(char * in_stream,
                          char * audio_samples);
int main()
{
 task load_stream_t(load_input_stream, in_stream);
 task extract_audio_t(extract_audio_samples,
                      __read_only(in_stream),
                         audio_samples);
  ...
  load_stream_t(); // or load_stream_t.run() to
}                  // to execute task
```

« Function as Task »

The XPU Programming Interface : Task Definition

```
class image
{
  public:
    int sharpen(int val);
    int blur(...);
  ...
};
int main( )
{
  image img(“img.jpg”);
  task sharpen_t(&img, &image::sharpen, 11);
}
```

« Class Method as Task »

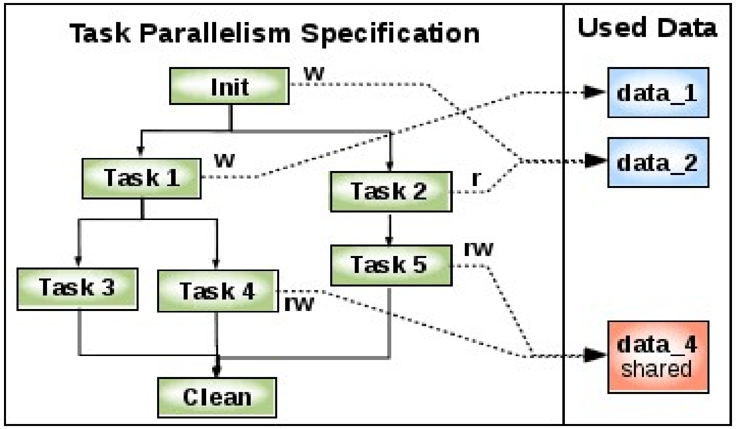
The XPU Programming Interface : Task Definition

```
int main( )
 {
  float * f;
  xpu::task low_pass([](float * samples, int freq) {...code... }, audio_samples, 7000);
 }
```

« Lambda Expression as Task (C++0x or greater)»

» The XPU Programming Interface : Task Parallelism

- Task parallelism can be specified at all levels of granularity using only two kerywords : “**parallel**” and “**sequential**”
- XPU is able to **extract transparently task-data dependencies**.
- XPU detect **automatically shared data accesses** by concurrent tasks and **protect it against potential race condition**.
- This same information can be used by the run-time system to perform **cache-aware scheduling** and reduce communication overhead.

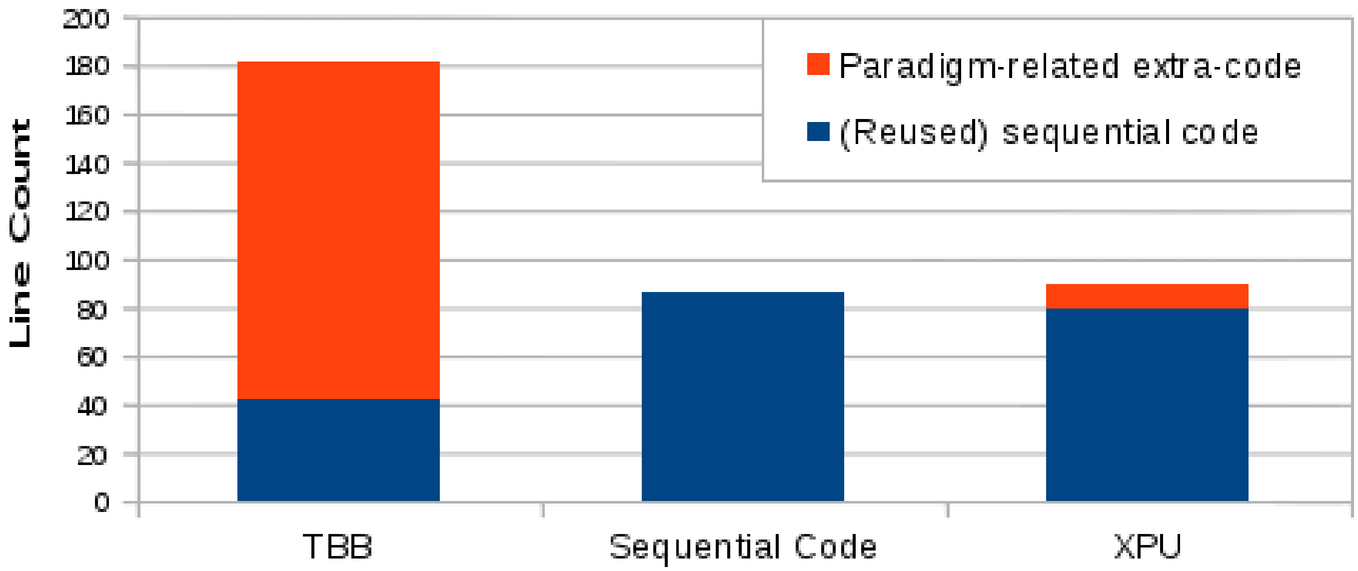



```
void main() {
 task t1(function, data_1),        // task definition
      t2(&o, cls::method, data_2), ...;
 task_group * program;
 program = parallel(sequential(t1, parallel(t3,t4)),
                    sequential(t2, t5));
 init();
 program->run(); // 'data_4' protected automatically
 clean();
}
```

» The XPU Programming Interface : Expressiveness & Programmability

- Expressiveness : XPU vs Threading Building Block
  - We consider a sequential application composed from 7 functions.
  - We count required extra-lines of code to express parallelism (as specified in the previous figure) and the number of reused lines of sequential code.

→ XPU requires much lesser extra-code to express parallelism and reuse most of the sequential code with negligible modifications.



The XPU Programming Interface : Temporal Parallelism

- An example of a 4-stages pipeline.
- Tasks are used as processing pipeline stages.

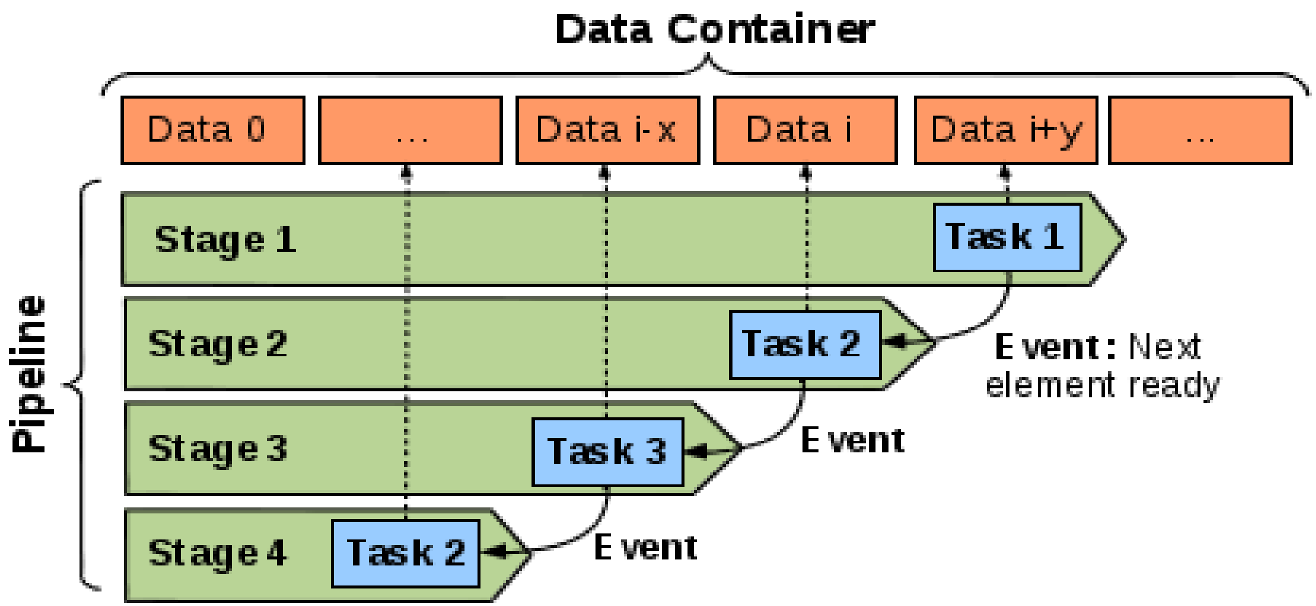
```
void sharpen(int i, vector<image> * imgs) // i = frame index
{ imgs[i]->sharpen(); }

void multiply(int i, vector<image> * imgs, image * mask)
{ imgs[i]->multiply(mask); }

int main()
{
  vector<image> frames(size);
  ...
  task sharpen_t(sharpen, 0, &frames),
       blur_t(blur, 0, &frames),
       multiply_t(multiply, 0, &frames, &mask);
  task_group * process_image = pipeline(size, sharpen_t,
                                              blur_t,
                                              contrast_t,
                                              multiply_t);
  process_image->run(); // frame index "i" will be updated
```

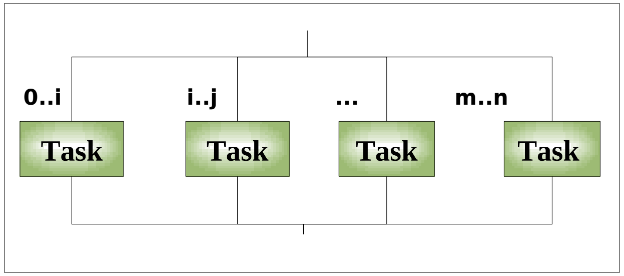
» The XPU Programming Interface : Temporal Parallelism

- Internal Pipeline Design : Transparent communication between processing stages through events .



The XPU Programming Interface : Data Parallelism

- Parallel For Loop
  - The XPU Intelligent Run-time system ensure dynamically scalable data partitioning on the underlying architecture.




```
int process(int from, int to, int step, image* images) {
  for (int i=from; i<to; i+=step)  ...
}
void main()
{
  image * images = … ;
  task process_t(process, 0,0,0, images);
  task_group * pf;
  pf = new parallel_for(0, image_count, 1, &process_t);
  pf->run();
}
```

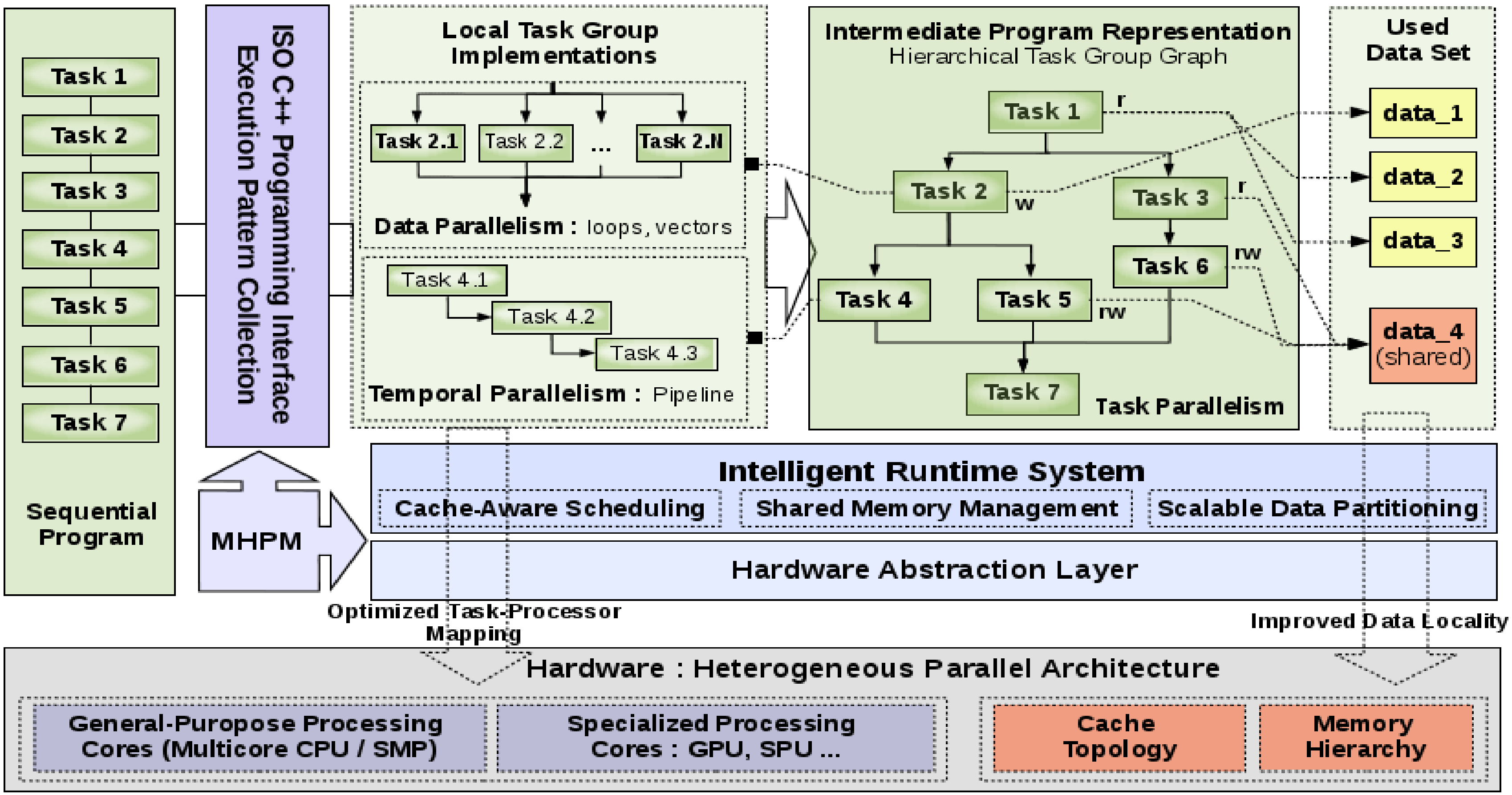
The XPU Programming Interface : Data Parallelism

- Parallel Vector
  - Express massive data parallelism on heterogeneous multicore architecture.
  - Generate transparently OpenCL kernel at run-time and manage transparently memory transfers and workload scheduling.
  - Not yet implemented as "task_group" ...

```
#define size 1000000
int main()
 {
   xpu::vector<float> A(size), B(size), C(size);
   A = B + C; // Transparent addition on GPU/CPU/FPGA...
}
```

» **Recapitulation : The MHPM Architecture**

» MHPM Architecture Overview



» Conclusion and Future Works

Conclusion Future Works

- The HTGG is rich program intermediate representation which encapsulate parallelism specification and task ordering and task-data dependencies.
- The hardware abstraction layer give us dynamically a description of the underlying architecture : available processing units, their execution capabilities and processor cache topology.

- **Cache-Aware Task Scheduling**

  We are trying to exploit this valuable information about both hardware architecture and task-data dependencies to design an efficient cache-aware scheduling which will dynamically improve spatial and temporal data locality.

- **Automatic Parallelization**

  Task-data dependencies can be also exploited to generate automatically the HTGG from a sequence of tasks or task groups.

  → Instead of building task execution graph manually (current version):

```
parallel(sequential(task1, task2), sequential(task3,...) ..., taskN)
```

  → we generate transparently the HTGG

```
parallelize(task1, task2, task3, ..., taskN
```

Thank You

Questions ?