Introduction to FastFlow programming

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Objectives

- Have a good idea of the FastFlow framework
  - how it works and its main features
  - also, weakness and strength points
- To be able to write simple (but not-trivial) parallel FastFlow programs

What is FastFlow

- FastFlow is a parallel programming framework written in C/C++ promoting pattern based parallel programming
- It is a joint research work between Computer Science Department of University of Pisa and Torino
- It aims to be usable, efficient and flexible enough for programming heterogeneous multi/many-cores platforms
  - multi-core + GPGPUs + Xeon PHI + FPGA …..
- FastFlow has also a distributed run-time for targeting cluster of workstations

Downloading and installing FastFlow

- Supports for Linux, Mac OS, Windows (Visual Studio)
  - The most stable version is the Linux one
    - we are going to use the Linux (x86_64) version in this course
- To get the latest svn version from Sourceforge

```
svn co https://svn.code.sf.net/p/mc-fastflow/code/  fastflow
```

  - creates a fastflow dir with everything inside (tests, examples, tutorial, ….)
- To get the latest updates just cd into the fastflow main dir and type:

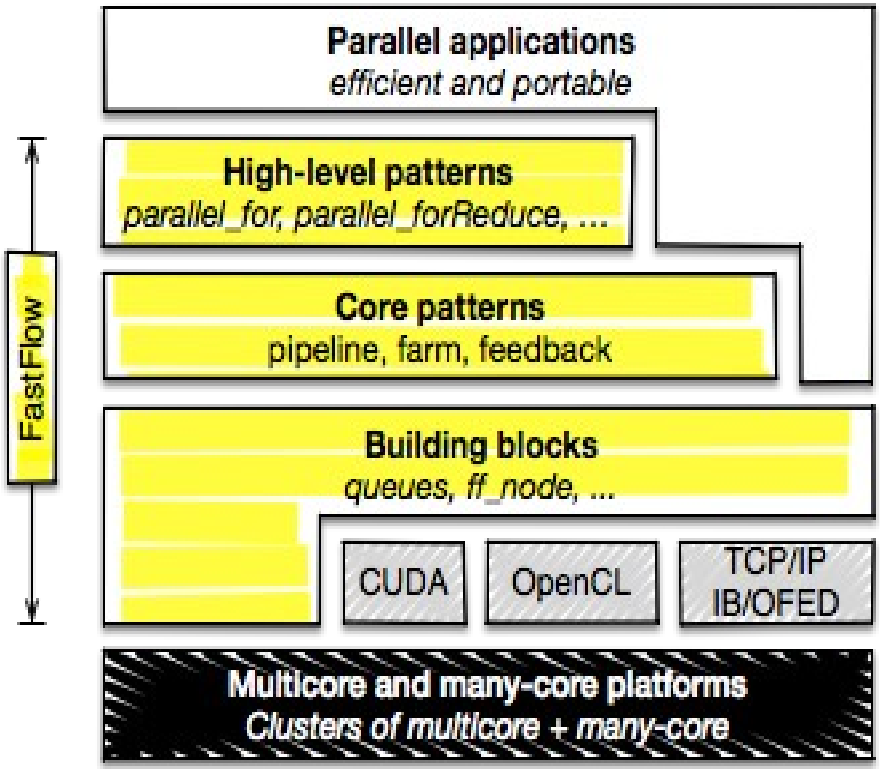
```
svn update
```

- The run-time (i.e. all you need for compiling your programs) is in the *ff* folder (i.e. *fastflow/ff*)
  - NOTE: FastFlow is a class library not a plain library
- You need: make, g++ (with C++11 support, i.e. version >= 4.7)

The FastFlow tutorial

- The FastFlow tutorial is available as pdf file on the FastFlow home page under "Tutorial"
  - http://mc-fastflow.sourceforge.net (aka calvados.di.unipi.it)
  - "FastFlow tutorial" ("PDF File")
- All tests and examples described in the tutorial are available as a separate tarball file: **fftutorial_source_code.tgz**
  - can be downloaded from the FastFlow home ("Tests and examples – source code tarball")
- In the tutorial source code there are a number of very simple examples covering almost all aspects of using pipeline, farm, ParallelFor, map, mdf.
  - Many features of the FastFlow framework are not covered in the tutorial yet
- There are also a number of small ("more complex") applications, for example: image filtering, block-based matrix multiplication, mandelbrot set computation, dot-product, etc...

The FastFlow layers

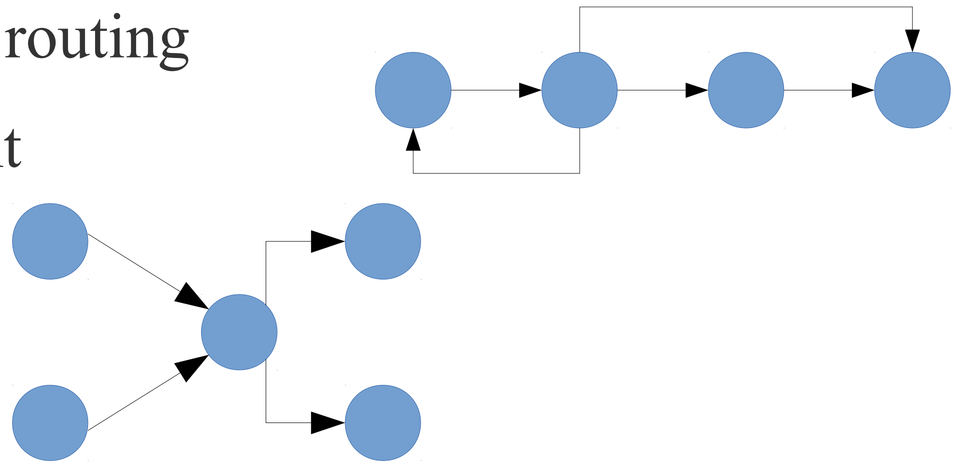


- C++ class library
- Promotes (high-level) structured parallel programming
- Streaming natively supported
- It aims to be flexible and efficient enough to target **multi-core**, **many-core** and **distributed heterogeneous systems**.
- Layered design:
  - **Building blocks** minimal set of mechanisms: channels, code wrappers, combinators.
  - **Core patterns** streaming patterns (*pipeline* and *task-farm*) plus the *feedback* pattern modifier
  - **High-level patterns** aim to provide flexible reusable parametric patterns for solving specific parallel problems

http://mc-fastflow.sourceforge.net
http://calvados.di.unipi.it/fastflow

The FastFlow concurrency model

- Data-Flow programming model implemented via shared-memory
  - Nodes are parallel activities. Edges are true data dependencies
  - Producer-Consumer synchronizations
  - More complex synchronizations are embedded into the patter behaviour
  - Data is not moved/copied if not really needed
- Full user's control of message routing
- Non-determinism management

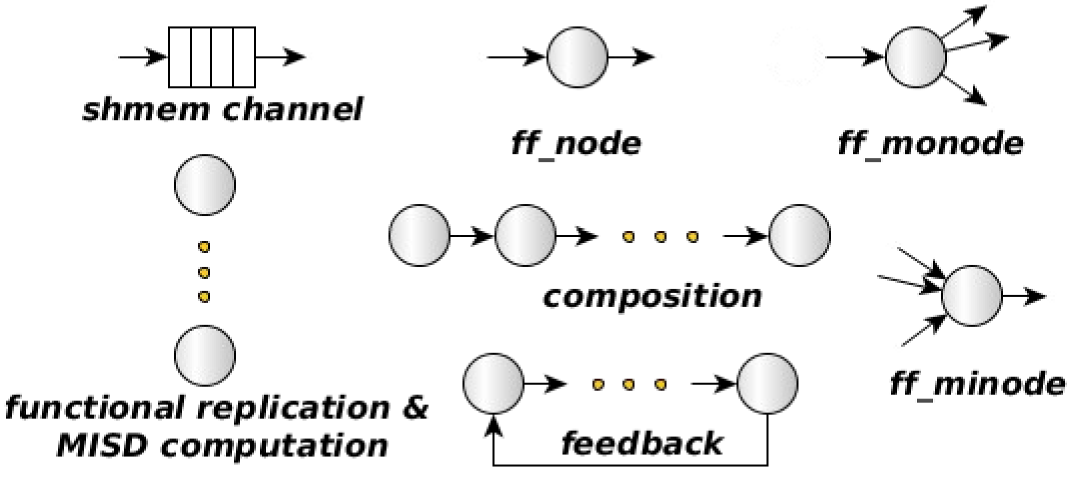


What FastFlow provides

- FastFlow provides patterns and skeletons
  - Pattern and algorithmic skeleton represent the same concept but at different abstraction level
- Stream-based parallel patterns (pipe, farm) plus a pattern modifier (feedback)
- Data-parallel patterns (map, stencil-reduce)
- Task-parallel pattern (async function execution, macro-data-flow, D&C)

- FastFlow does not provide implicit memory management of data structures
  - In almost all patterns, memory management is left to the user
  - Memory management is a very critical point for performance

Building blocks



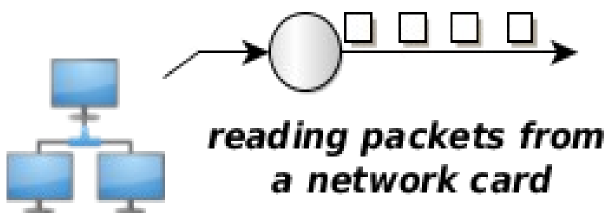
- Minimal set of efficient mechanisms and functionalities
- Nodes are concurrent entities (i.e. POSIX threads)
- Arrows are channels implemented as SPSC lock-free queue
  - bounded or unbounded in size

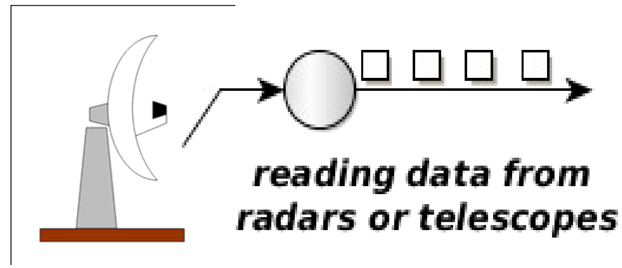
Stream concept (recap)

- Sequence of values (possibly infinite), coming from a source, having the same data type
  - Stream of images, stream of network packets, stream of matrices, stream of files, …..
- A streaming application can be seen as a work-flow *graph* whose nodes are computing nodes (sequential or parallel) and arcs are channels bringing streams of data.
- Streams may be either "*primitive*" (i.e. coming from HW sensors, network interfaces, ….) or can be generated internally by the application ("*fake stream*")
- Typically in a stream based computation the first stage receives (or reads) data from a source and produces tasks for next stages.

Real and Fake streams

- "*real streams*"



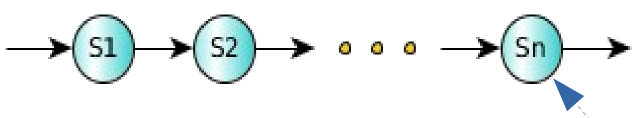


  - In these cases it is really important to satisfy minimum processing requirements (bandwidth, latency, etc...) in order to not lose data coming from the source
- "*fake streams*": streams produced by unrolling loops
  - You don't have an "infinite" source of data
  - The source is a software module
  - Typically less stringent constraints

```
for(i=start; i<stop; i+=step)
   allocate data for a task
   create a task
   send out the task
```

Stream Parallel Patterns in FastFlow ("core" patterns)

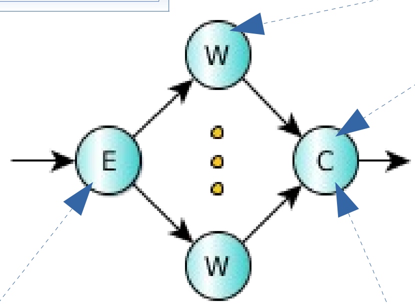
pipeline




```
ff_Pipe<myTask> pipe(S1,S2,...,Sn);
pipe.run_and_wait_end();
```

ff_node

task-farm



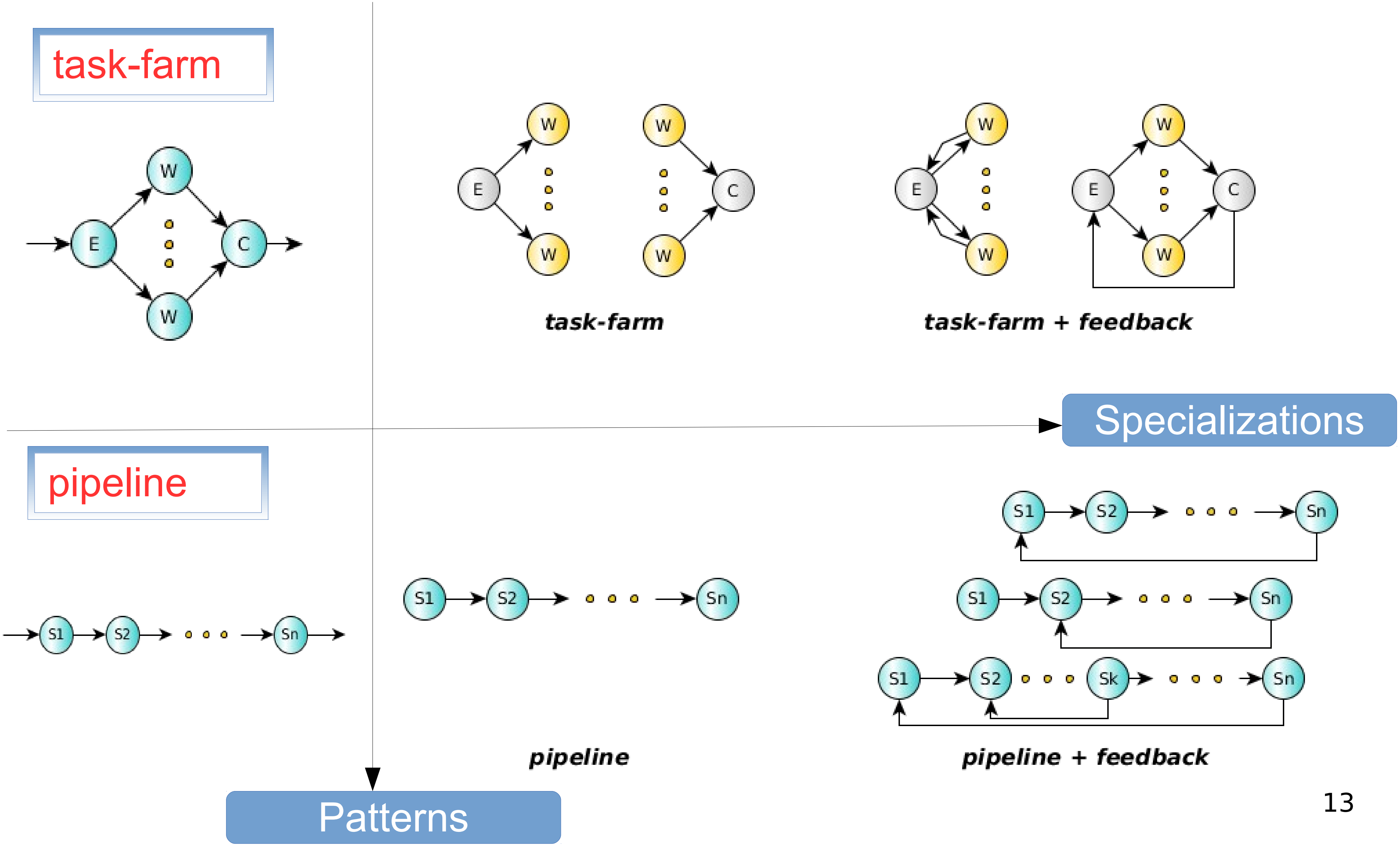

```
std::vector<std::unique_ptr<ff_node> >  Warray;

ff_Farm<myTask> farm(std::move(Warray),E, C);
farm.run_and_wait_end();
```

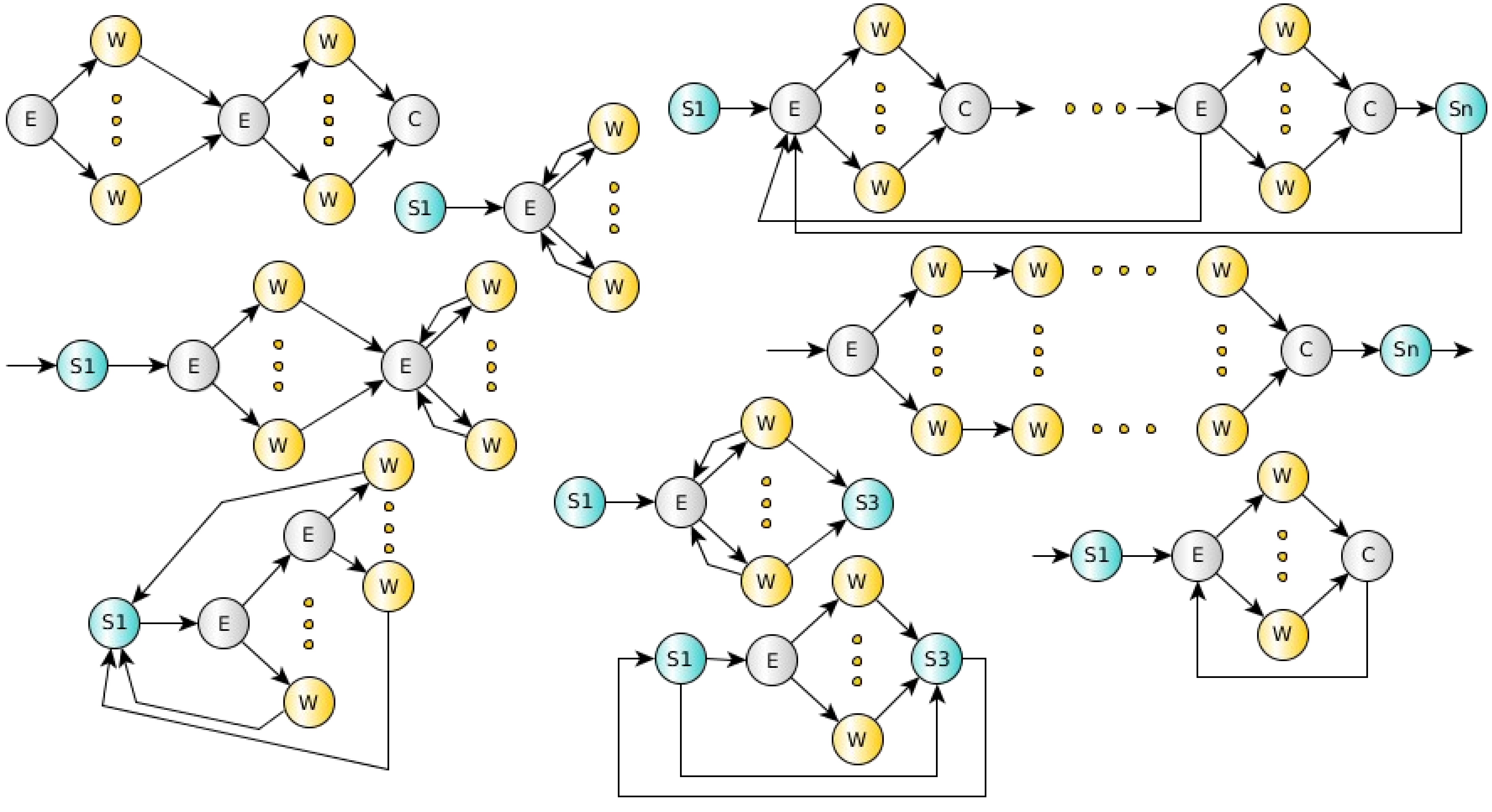
Emitter:
schedules input data items

Collector:
gathers results

Stream Parallel Patterns ("core" patterns)



Core patterns composition



pipeline + task-farm + feedback

High-Level Patterns

- Address application programmers' needs
- All of them are implemented on top of “core” patterns
  - Stream Parallelism: Pipe, Farm
  - Data Parallelism: Map, IterativeStencilReduce
  - Task Parallelism: PoolEvolution, MDF, TaskF, D&C
  - Loop Parallelism: ParallelFor, ParallelForReduce

Core patterns: sequential *ff_node*

code wrapper pattern

```
struct myNode: ff_node_t<TIN,TOUT> {
 int svc_init() { // optional
  // called once for initialization purposes
  return 0;  // <0 means error
 }
 TOUT *svc(TIN * task) {
  // do something on the input task
  // called each time a task is available
  return task; // also EOS, GO_ON, ….
 };
 void svc_end() {
  // called once for termination purposes
  // called if EOS is either received in input
  // or it is generated by the node
 }
};
```

- **A sequential *ff_node* is an active object (thread)**
- Input/Output tasks (stream elements) are memory pointers
- The user is responsible for memory allocation/deallocation of data items
  - FF provides a memory allocator (not introduced here)
- Special return values:
  - ***EOS*** means End-Of-Stream
  - ***GO_ON*** means "I have no more tasks to send out, give me another input task (if any)"

ff_node: generating and absorbing tasks

code wrapper pattern

```
struct myNode1: ff_node_t<Task> {
 Task *svc(Task *) {
    // generates N tasks and then EOS
    for(long i=0;i<N; ++i) {
      ff_send_out(new Task);
     }
    return EOS;
 };
};
```

```
struct myNode2: ff_node_t<Task> {
 Task *svc(Task * task) {
    // do something with the task
    do_Work(task);
    delete task;
    return GO_ON; // it does not send out task
 };
};
```

- Typically myNode1 is the first stage of a pipeline, it produces tasks by using the ***ff_send_out*** method or simply returning task from the svc method
- Typically myNode2 is the last stage of a pipeline computation, it gets in input tasks without producing any outputs

Core patterns: *ff_Pipe*

pipeline pattern

```
struct myNode1: ff_node_t<myTask> {
 myTask *svc(myTask *) {
      for(long i=0;i<10;++i)
         ff_send_out(new myTask(i));
      return EOS;
}};
struct myNode2: ff_node_t<myTask> {
 myTask *svc(myTask *task) {
      return task;
}};
struct myNode3: ff_node_t<myTask> {
 myTask *svc(myTask* task) {
      f3(task);
      return GO_ON;
}};
myNode1 _1;
myNode2 _2;
myNode3 _3;
ff_Pipe<> pipe(_1,_2,_3);
pipe.run_and_wait_end();
```

- *pipeline* stages are *ff_node*(s)
- A *pipeline* itself is an *ff_node*
  - It is easy to build pipe of pipe
- **ff_send_out** can be used to generate a stream of tasks
- Here, the first stage generates 10 tasks and then EOS
- The second stage just produces in output the received task
- Finally, the third stage applies the function f3 to each stream element and does not return any tasks

Simple *ff_Pipe* example

- Let's take a look at a simple test in the FastFlow tutorial:
  - hello_pipe.cpp

- How to compile:
  - Suppose we define the env var FF_HOME as (bash shell):
    - *export FF_HOME=$HOME/fastflow*
  - *g++ -std=c++11 -Wall **-O3** -I $FF_HOME hello_pipe.cpp -o hello_pipe -pthread*
  - *On the Xeon PHI:*
    - *g++ -std=c++11 -Wall **-DNO_DEFAULT_MAPPING -O3** -I $FF_HOME hello_pipe.cpp -o hello_pipe -pthread*