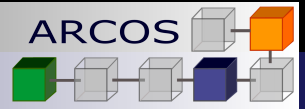

An introduction to **GrPPI**

Generic Reusable Parallel Patterns Interface

J. Daniel Garcia

ARCOS Group
University Carlos III of Madrid
Spain

November 2019

Warning

ARCOS@uc3m

- **UC3M**: A young international research oriented university.
- **ARCOS**: An applied research group.
  - Lines: High Performance Computing, Big data, Cyberphysical Systems, and **Programming models for application improvement**.
- **Programming Models for Application Improvement**:
  - Provide programming tools for **improving**:
    - Performance.
    - Energy efficiency.
    - Maintainability.
    - Correctness.
- **Standardization**:
  - **ISO/IEC JTC/SC22/WG21**. ISO C++ standards committe.

Acknowledgements

- Project 801091 **"ASPIDE: Exascale programming models for extreme programming** funded by the European Commission through H2020 FET-HPC (2018-2020).
- Project ICT 644235 **"REPHRASE: REfactoring Parallel Heterogeneous Resource-aware Applications"** funded by the European Commission through H2020 program (2015-2018).
- Project TIN2016-79673-P **"Towards Unification of HPC and Big Data Paradigms"** funded by the Spanish Ministry of Economy and Competitiveness (2016-2019).

GrPPI team

- **Main team**
  - J. Daniel Garcia (UC3M, lead).
  - Javier Garcia Blas (UC3M).
  - David del Río (UC3M).
  - Javier Fernández (UC3M).
- **Cooperation**
  - Marco Danelutto (Univ. Pisa)
  - Massimo Torquati (Univ. Pisa)
  - Marco Aldinucci (Univ. Torino)
  - Fabio Tordini (Univ. Torino)
  - Plácido Fernández (UC3M-CERN).
  - Manuel F. Dolz (Univ. Jaume I).
  - ...

Sequential Programming versus Parallel Programming

- **Sequential programming**
  - Well-known set of *control-structures* embedded in programming languages.
  - Control structures inherently sequential.

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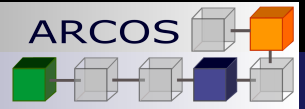
Sequential Programming versus Parallel Programming

- **Sequential programming**
  - Well-known set of *control-structures* embedded in programming languages.
  - Control structures inherently sequential.
- **Traditional Parallel programming**
  - Constructs *adapting* sequential control structures to the parallel world (e.g. *parallel-for*).
- **But wait!**
  - What if we had **constructs** that could be **both** sequential and parallel?



Software design

There are two ways of constructing a software design:

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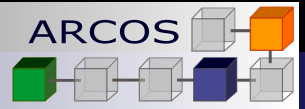

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*to make it **so simple** that there are **obviously no deficiencies**,*

and the other way is
*to make it **so complicated** that there are **no obvious deficiencies**.*

*The **first method** is **far more difficult**.*

C.A.R Hoare

Adding two vectors

Traditional way

```
using numvec = std::vector<double>;

numvec add(const numvec & v1, const numvec & v2) {
  numvec res;
  res.reserve(v1.size()) ; // Asume equal sizes
  for (int i =0; i <v1.size() ; ++i) {
    res.push_back(v1[i]+v2[i]) ;
  }
  return res;
}
```

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```

- Adds additional constraints.
  - Traversing in-order.
- Potential mistakes.
  - **i<v1.size()** versus **i<=v1.size()**.

Adding two vectors

The STL way (C++98/03)

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using numvec = std::vector<double>;

numvec add(const numvec & v1, const numvec & v2) {
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- Minimize off-by-one mistakes.
- Type specific optimizations.

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The STL way (C++14)

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  return res;
}
```

- Use (possibly generic) lambdas .

A brief history of patterns

- From building and architecture (Cristopher Alexander):
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- To parallel programming (McCool, Reinders, Robinson):
  - **2012**: Structured Parallel Programming: Patterns for Efficient Computation.

Parallel Patterns

- Levels of patterns:
  - Software Architecture Patterns.
  - Design Patterns.
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  - Implementation patterns.

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- **Algorithm Strategy Pattern** or **Algorithmic Skeleton**
  - A way to codify best practices in **parallel programming** in a **reusable way**.

- A single **Parallel Pattern** may have **different realizations** in **different programming models**.

Example: map pattern

- Apply a single **elemental operation** to different **data items**.

SAXPY: Sequential

```
for (size_t i=0; i<n; ++i) {
  y[i] = a * x[i] + y[i];
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}
```
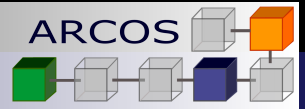

SAXPY: TBB

```
tbb::parallel_for (tbb::blocked_range<int>{0,n},
  [&](tbb::blocked_range<int> r) {
    for (auto i : r) {
      y[i] = a * x[i] + y[i];
    }
  });
```



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- **Multiple back-ends** should be offered with **simple switching** mechanisms.
- Interface should **integrate** seamlessly with **modern C++** and its standard library.
- Applications should be able to **take advantage** of **modern C++** language features.

C++17: Execution policies

- An **execution policy** allows to disambiguate parallel algorithms overloads.
  - **sequenced_policy**: Not parallelized.
    - **std::execution::seq**.
  - **parallel_policy**: Execution can be parallelized in multiple threads.
    - **std::execution::par**.
  - **parallel_unsequenced_policy**: Execution can be parallelized, vectorized, or migrated across threads.
    - **std::execution::par_unseq**.

C++17: Parallel algorithms

- Most algorithms in **<algorithm>** and **<numeric>** have **execution policy** based versions.

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```
std::transform(std::execution::par,
  y.begin(), y.end(), x.begin(), y.begin(),
  [=](auto vx, auto vy) { return a * vx + vy; });
```

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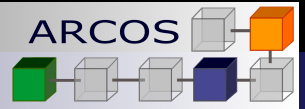
```
std::transform(std::execution::par,
  y.begin(), y.end(), x.begin(), y.begin(),
  [=](auto vx, auto vy) { return a * vx + vy; });
```

- However ...
  - No fine control knobs.
  - Lack of task parallelism and stream parallelism.
  - OK as an entry level to parallelism.



GrPPI

https://github.com/arcosuc3m/grppi

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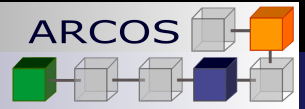
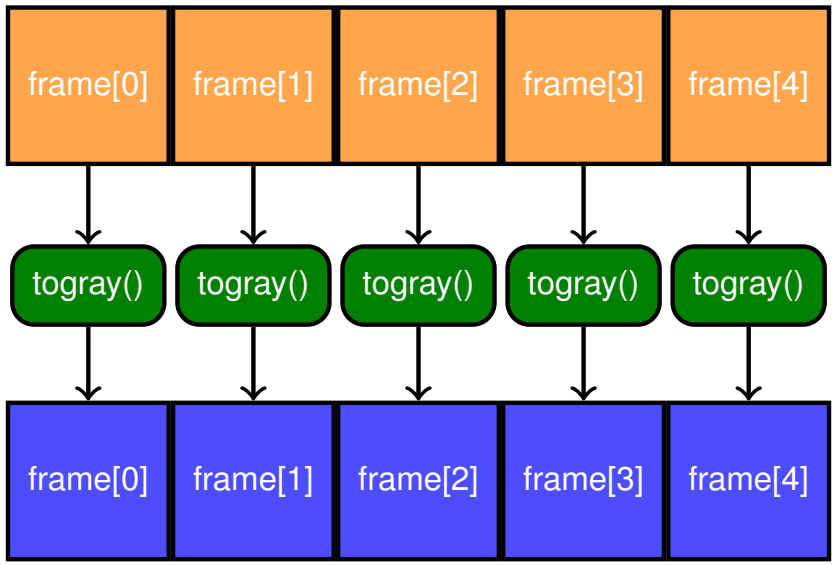
- **G**eneric **r**eusable **P**arallel **P**attern **Interface**.
  - A header only library (might change).
  - A set of execution policies.
  - A set of type safe generic algorithms.
  - Requires **C++14**.
  - Apache 2.0 License.



Example: Transforming a sequence

- Given a sequence of **frame**s generate a new sequence of frames in grayscale.

```
struct frame { /* ... */ };
frame togray(const frame & f);
```



Transforming a sequence

Traditional explicit loop

```
using frameseq = std::vector<frame>;

frameseq seq_togray(const frameseq & s) {
  frameseq r;
  r.reserve(s.size());

  // Requires processing in-order
  for (const auto & f : s) {
    r.push_back(togray(f));
  }
  return r;
}
```

Transforming a sequence

STL way

```
using frameseq = std::vector<frame>;

frameseq seq_togray(const frameseq & s) {
  frameseq r;
  r.reserve(s.size());

  std::transform(s.begin(), s.end(), std::back_inserter(r), togray);

  return r;
}
```

Transforming a sequence

Parallel STL way (C++17)

```
using frameseq = std::vector<frame>;

frameseq seq_togray(const frameseq & s) {
  frameseq r;
  r.reserve(s.size()) ;

  // No execution order assumed
  std::transform(std::execution::par,
      s.begin(), s.end(), std::back_inserter(r), togray);

  return r;
}
```

Transforming a sequence

GrPPI

```
using frameseq = std::vector<frame>;

frameseq seq_togray(const frameseq & s) {
  frameseq r(s.size());

  grppi::sequential_execution seq;
  grppi::map(seq, s.begin(), s.end(), r.begin(), togray);

  return r;
}
```

Transforming a sequence

GrPPI + lambda

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using frameseq = std::vector<frame>;

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  grppi::map(seq, s.begin(), s.end(), r.begin(),
    [](const frame & f) { return filter(f,64); });

  return r;
}
```

Transforming a sequence

GrPPI + lambda - iterators

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using frameseq = std::vector<frame>;

frameseq seq_togray(const frameseq & s) {
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```

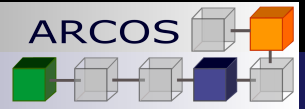

3 Patterns in GrPPI

- Controlling execution
- Patterns overview
- Data patterns
- Streaming patterns

Execution types

- Execution model is encapsulated in execution types.
  - Always provided as first argument to patterns.

- Current concrete execution types:
  - **Sequential**: **sequential_execution**.
  - **ISO C++ Threads**: **parallel_execution_native**.
  - **OpenMP**: **parallel_execution_omp**.
  - **Intel TBB**: **parallel_execution_tbb**.
  - **FastFlow**: **parallel_execution_ff**.

- Run-time polymorphic wrapper through type erasure:
  - **dynamic_execution**.

Execution model properties

- Some execution types allow finer configurtion.
  - Example: Concurrency degree.

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  - Example: Concurrency degree.

- Interface:

```
ex.set_concurrency_degree(4);
int n = ex.concurrency_degree();
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  - Example: Concurrency degree.

- Interface:

```
ex.set_concurrency_degree(4);
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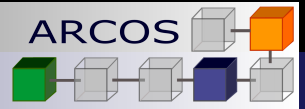
```

- **Default values**:
  - **Sequential** ⇒ **1**.
  - **Native** ⇒ **std::thread::hardware_concurrency()**.
  - **OpenMP** ⇒ **omp_get_num_threads()**.



A classification

- **Data patterns**: Express computations over a data set.
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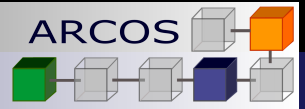
- **Data patterns**: Express computations over a data set.
  - **map**, **reduce**, **map/reduce**, **stencil**.
- **Task patterns**: Express task composition.
  - **divide/conquer**.
- **Streaming patterns**: Express computations ver a (possibly unbounded) data set.
  - **pipeline**.
  - Specialized stages: **farm**, **filter**, **reduction**, **iteration**.



Patterns on data sets

- A **data pattern** performs an operation on one or more data sets that are already in memory.

- **Input**:
  - One or more data sets.
  - Operations.

- **Output**:
  - A data set (**map**, **stencil**).
  - A single value (**reduce**, **map/reduce**).

Maps on data sequences

- A **map** pattern applies an operation to every element in a a data set, generating a new data set.

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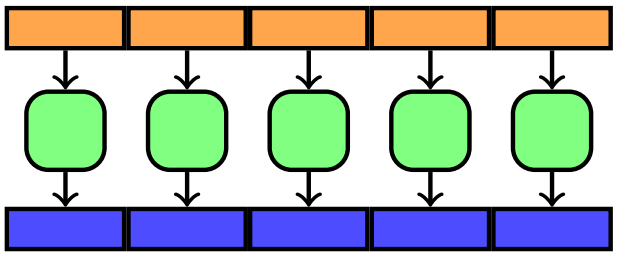
- **Unidimensional**:



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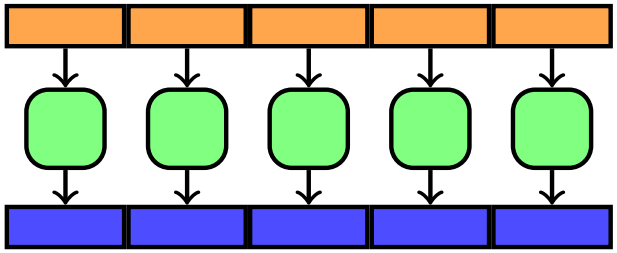
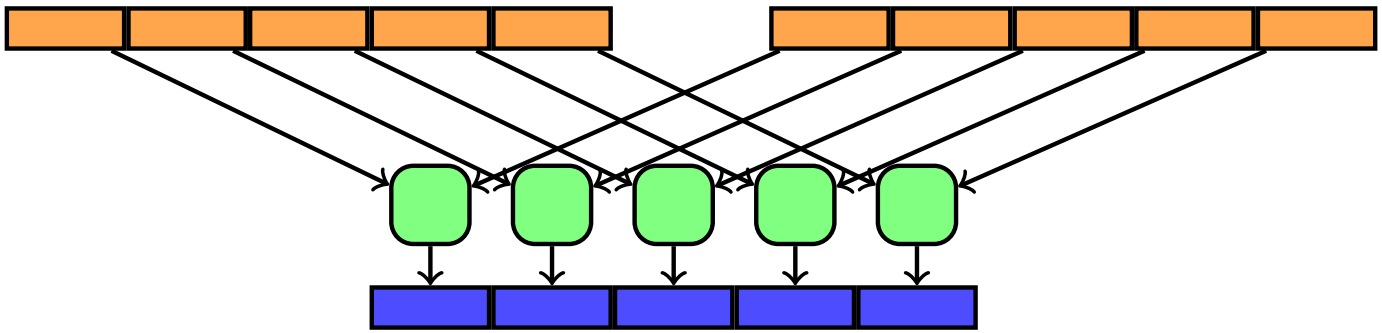


- **Multidimensional**:



Single sequences mapping

Double all elements in vector sequentially

```
std::vector<double> double_elements(const std::vector<double> & v)
{
  std::vector<double> res(v.size());
  grppi::sequential_execution seq;

  grppi::map(seq, v, res,
    [](double x) { return 2*x; });

  return res;
}
```

Single sequences mapping

Double all elements in vector with OpenMP

```
std::vector<double> double_elements(const std::vector<double> & v)
{
  std::vector<double> res(v.size());
  grppi::parallel_execution_omp omp;

  grppi::map(omp, v, res,
    [](double x) { return 2*x; });

  return res;
}
```

Multiple sequences mapping

Add two vectors

```
template <typename Execution>
std::vector<double> add_vectors(const Execution & ex,
                                const std::vector<double> & v1,
                                const std::vector<double> & v2)
{
  auto size = std::min(v1.size(), v2.size());
  std::vector<double> res(size);

  grppi::map(ex, zip(v1, v2), res,
    [](double x, double y) { return x+y; });

  return res;
}
```

Multiple sequences mapping

Add three vectors

```
template <typename Execution>
std::vector<double> add_vectors(const Execution & ex,
                                const std::vector<double> & v1,
                                const std::vector<double> & v2,
                                const std::vector<double> & v3)
{
  auto size = std::min(v1.size(), v2.size());
  std::vector<double> res(size);

  grppi::map(ex, zip(v1,v2,v3), res,
    [](double x, double y, double z) { return x+y+z; });

  return res;
}
```

Heterogeneous mapping

- The result can be from a different type.

Complex vector from real and imaginary vectors

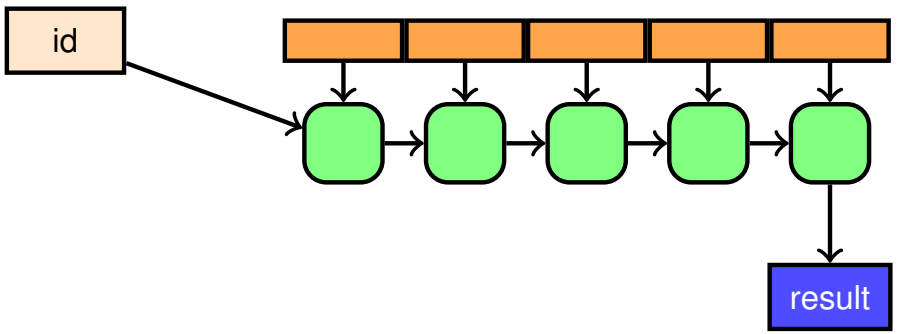
```
template <typename Execution>
std::vector<complex<double>> create_cplx(const Execution & ex,
                                         const std::vector<double> & re,
                                         const std::vector<double> & im)
{
  auto size = std::min(re.size(), im.size());
  std::vector<complex<double>> res(size);

  grppi::map(ex, zip(re,im), res,
    [](double r, double i) -> complex<double> { return {r,i}; });

  return res;
}
```

Reductions on data sequences

- A **reduce** pattern combines all values in a data set using a binary combination operation.



Homogeneous reduction

Add a sequence of values

```
template <typename Execution>
double add_sequence(const Execution & ex, const vector<double> & v)
{
  return grppi::reduce(ex, v,  0.0,
    []( double x, double y) { return x+y; }) ;
}
```

Heterogeneous reduction

Add areas of shapes

```
template <typename Execution>
double add_areas(const Execution & ex, const std::vector<shape> & shapes)
{
  return grppi::reduce(ex, shapes, 0.0,
    []( double a, const auto & s) {
      return a + s.area()();
    });
}
```

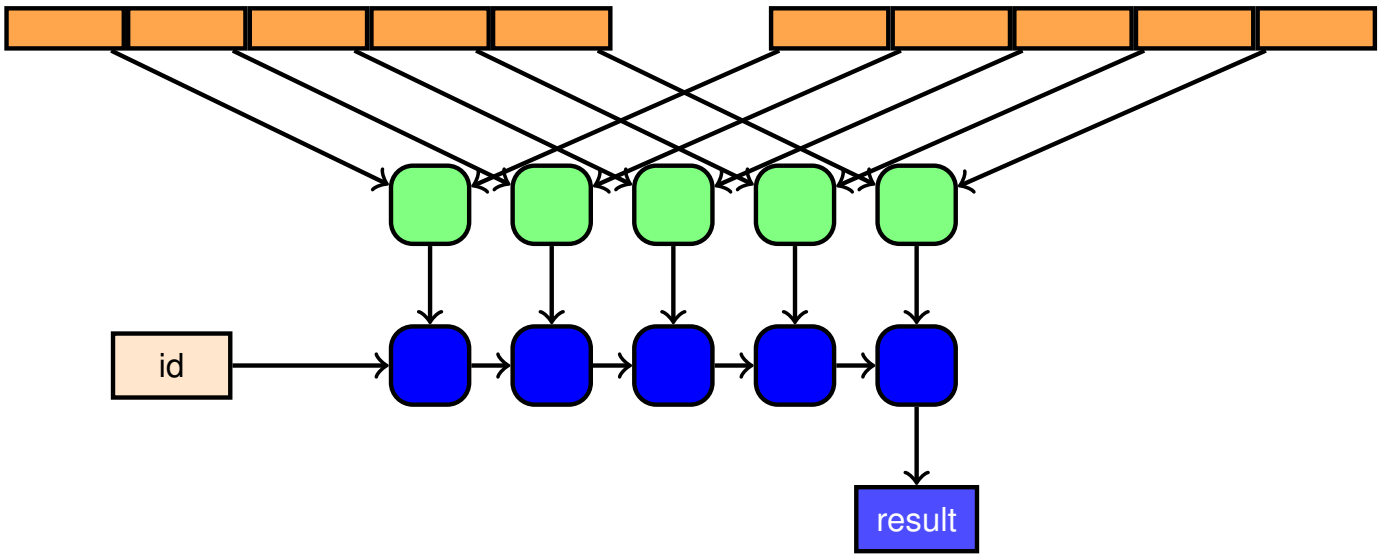
- **Note**: Better expressed as a map reduce.

Map/reduce pattern

- A **map/reduce** pattern combines a **map** pattern and a **reduce** pattern into a single pattern.
  1. One or more data sets are **mapped** applying a transformation operation.
  2. The results are combined by a **reduction** operation.

- A **map/reduce** could be also expressed by the composition of a **map** and a **reduce**.
  - However, **map/reduce** may potentially fuse both stages, allowing for extra optimizations.

Map/reduce



Single sequence map/reduce

Sum of squares

```
template <typename Execution>
double sum_squares(const Execution & ex, const std::vector<double> & v)
{
  return grppi::map_reduce(ex, v, 0.0,
    [](double x) { return x*x; }
    [](double x, double y) { return x+y; }
  );
}
```

Map/reduce on two data sets

Scalar product

```
template <typename Execution>
double scalar_product(const Execution & ex,
                      const std::vector<double> & v1,
                      const std::vector<double> & v2)
{
  return grppi::map_reduce(ex, zip(v1,v2), 0.0,
      []( double x, double y) { return x*y; },
      []( double x, double y) { return x+y; }) ;
}
```

Heterogeneous reduction versus map/reduce

Add areas of shapes

```
template <typename Execution>
int  add_areas(const Execution & ex, const std::vector<shape> & shapes)
{
   return grppi::map_reduce(ex, shapes, 0.0,
      []( const auto & s) { return s.area(); },
      []( double a, double b) { return a+b; } );
}
```

- **Note**: Better than previous **heterogeneous reduce**.

Cannonical map/reduce

- Given a sequence of words, produce a container where:
  - The key is the word.
  - The value is the number of occurrences of that word.

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Word frequencies

```
template <typename Execution>
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Word frequencies

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template <typename Execution>
auto word_freq(const Execution & ex, const std::vector<std::string> & words)
{
  using namespace std;
  using dictionary = std::map<string,int>;
```

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{
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  using dictionary = std::map<string,int>;
  return grppi::map_reduce(ex, words, dictionary{},
```

Cannonical map/reduce

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Word frequencies

```
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  return grppi::map_reduce(ex, words, dictionary{},
    [](string w) -> dictionary { return {w,1}; }
```

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Word frequencies

```
template <typename Execution>
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{
  using namespace std;
  using dictionary = std::map<string,int>;
  return grppi::map_reduce(ex, words, dictionary{},
      [](string w) -> dictionary { return {w,1}; }
      [](dictionary & lhs, const dictionary & rhs) -> dictionary {
        for (auto & entry : rhs) { lhs[entry.first] += entry.second; }
        return lhs;
      });
}
```
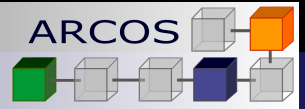
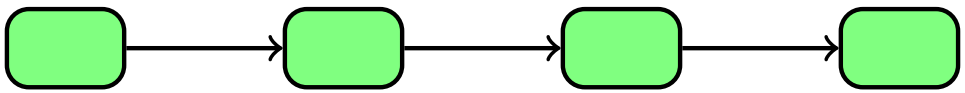



3 Patterns in GrPPI

- Controlling execution
- Patterns overview
- Data patterns
- Streaming patterns

Pipeline pattern

- A **pipeline** pattern allows processing a data stream where the computation may be divided in multiple stages.
  - Each stage processes the data item generated in the previous stage and passes the produced result to the next stage.



Standalone pipeline

- A **standalone pipeline** is a top-level pipeline.
  - Invoking the pipeline translates into its execution.

Standalone pipeline

- A **standalone pipeline** is a top-level pipeline.
  - Invoking the pipeline translates into its execution.

- Given:
  - A **generator** $g : \varnothing \mapsto T_1 \cup \varnothing$
  - A sequence of **transformers** $t_i : T_i \mapsto T_{i+1}$

- For every **non-empty** value generated by g, it evaluates:
  - $t_n(t_{n-1}(\ldots t_1(g())))$

Generators

- A generator *g* is any callable C++ entity that:
  - Takes no argument.
  - Returns a value of type *T* that may hold (or not) a value.
  - Null value signals end of stream.

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```
T x = g();
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    ```
    T x = g();
    ```

  - Is contextually convertible to **bool**

    ```
    if (x) { /* ... */ }
    if (!x) { /* ... */ }
    ```

Generators

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    T x = g();
    ```

  - Is contextually convertible to **bool**

    ```
    if (x) { /* ... */ }
    if (!x) { /* ... */ }
    ```

  - Can be derreferenced

    ```
    auto val = *x;
    ```

Generators

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  - Takes no argument.
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    ```
    T x = g();
    ```

  - Is contextually convertible to **bool**

    ```
    if (x) { /* ... */ }
    if (!x) { /* ... */ }
    ```

  - Can be derreferenced

    ```
    auto val = *x;
    ```

- The standard library offers an excellent candidate **std::experimental::optional<T>**.

Simple pipeline

x -> x*x -> 1/x -> print

```
template <typename Execution>
void run_pipe(const Execution & ex, int n)
{
  grppi :: pipeline (ex,
    [i=0,max=n] () mutable -> optional<int> {
      if (i<max) return i++;
      else return {};
    },
    []( int x) -> double { return x*x; },
    []( double x) { return 1/x; },
    []( double x) { cout << x << "\n"; }
  );
}
```

Nested pipelines

- **Pipelines** may be **nested**.
- An **inner pipeline**:
  - Does not take an execution policy.
  - All stages are transformers (no generator).
  - The last stage must also produce values.
- The **inner pipeline** uses the same execution policy than the outer pipeline.

Nested pipelines

Image processing

```
void process(std::istream & in_file, std::ostream & out_file) {
  grppi::parallel_execution_native ex;
```

Nested pipelines

Image processing

```
void process(std::istream & in_file , std :: ostream & out_file) {
  grppi:parallel_execution_native ex;
  grppi :: pipeline (ex,
```

Nested pipelines

Image processing

```
void process(std::istream & in_file , std::ostream & out_file) {
  grppi:parallel_execution_native ex;
  grppi::pipeline(ex,
    [& in_file ]() -> optional<frame> {
      frame f = read_frame(file);
      if (! file ) return {};
      return f;
    },
```

Nested pipelines

Image processing

```
void process(std::istream & in_file , std::ostream & out_file) {
  grppi:parallel_execution_native ex;
  grppi::pipeline(ex,
    [& in_file ]() -> optional<frame> {
      frame f = read_frame(file);
      if (! file ) return {};
      return f;
    },
    pipeline(
      []( const frame & f) { return filter (f); },
      []( const frame & f) { return gray_scale(f); },
    },
```

Nested pipelines

Image processing

```
void process(std::istream & in_file , std::ostream & out_file) {
  grppi:parallel_execution_native ex;
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    [& in_file ]() -> optional<frame> {
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      if (! file ) return {};
      return f;
    },
    pipeline(
      []( const frame & f) { return filter (f); },
      []( const frame & f) { return gray_scale(f); },
    },
    [& out_file ](const frame & f) { write_frame(out_file , f); }
  );
}
```

Piecewise pipelines

Image processing

```
void process(std::istream & in_file, std::ostream & out_file) {
```

Piecewise pipelines

Image processing

```
void process(std::istream & in_file , std :: ostream & out_file) {
  auto reader = [& in_file ]() -> optional<frame> {
    frame f = read_frame(file);
    if (! file ) return {};
    return f;
  };
```

Piecewise pipelines

Image processing

```
void process(std::istream & in_file , std :: ostream & out_file) {
  auto reader = [& in_file ]() -> optional<frame> {
    frame f = read_frame(file);
    if (! file ) return {};
    return f;
  };
  auto transformer = pipeline(
    []( const frame & f) { return filter (f); },
    []( const frame & f) { return gray_scale(f); },
  };
```

Piecewise pipelines

Image processing

```
void process(std::istream & in_file, std::ostream & out_file) {
  auto reader = [&in_file]() -> optional<frame> {
    frame f = read_frame(file);
    if (!file) return {};
    return f;
  };
  auto transformer = pipeline(
    [](const frame & f) { return filter(f); },
    [](const frame & f) { return gray_scale(f); },
  );
  auto writer = [&out_file](const frame & f) { write_frame(out_file, f); }
```

Piecewise pipelines

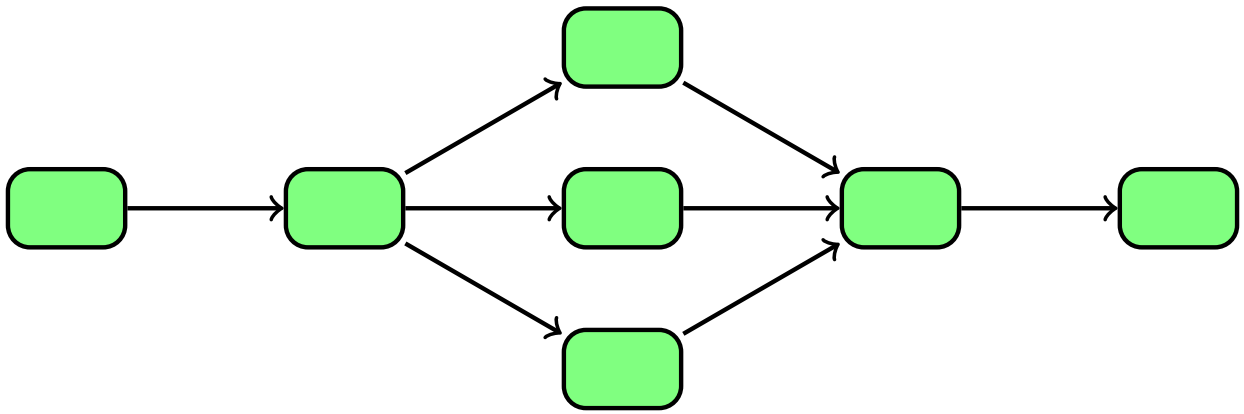
Image processing

```
void process(std::istream & in_file, std::ostream & out_file) {
  auto reader = [&in_file]() -> optional<frame> {
    frame f = read_frame(file);
    if (!file) return {};
    return f;
  };
  auto transformer = pipeline(
    [](const frame & f) { return filter(f); },
    [](const frame & f) { return gray_scale(f); },
  };
  auto writer = [&out_file](const frame & f) { write_frame(out_file, f); }

  grppi::parallel_execution_native ex;
  grppi::pipeline(ex, reader, transformer, writer);
}
```

Farm pattern

- A **farm** is a streaming pattern applicable to a stage in a **pipeline**, providing multiple tasks to process data items from a data stream.
  - A **farm** has an associated **cardinality** which is the number of parallel tasks used to serve the stage.
  - Each task in a **farm** runs a **transformer** for each data item it receives.



Farms in pipelines

Improving a video

```
template <typename Execution>
void run_pipe(const Execution & ex, std::ifstream & filein , std::ofstream & fileout )
{
  grppi::pipeline(ex,
    [& filein ] () -> optional<frame> {
      frame f = read_frame(filein);
      if (! filein ) retrun {};
      return f;
    },
    farm(4, []( const frame & f) { return improve(f); },
    [& fileout ] (const frame & f) { write_frame(f); }
  );
}
```

Piecewise farms

Improving a video

```
template <typename Execution>
void run_pipe(const Execution & ex, std::ifstream & filein , std::ofstream & fileout )
{
  auto improver = farm(4, []( const frame & f) { return improve(f); });

  grppi::pipeline(ex,
    [& filein ] () -> optional<frame> {
      frame f = read_frame(filein);
      if (! filein ) retrun {};
      return f;
    },
    improver,
    [& fileout ] (const frame & f) { write_frame(f); }
  );
}
```

Ordering

- Signals if pipeline items must be consumed in the same order they were produced.
  - Do they need to be *time-stamped*?
- Default is **ordered**.
- **API**
  - **ex.enable_ordering()**
  - **ex.disable_ordering()**
  - **bool** o = **ex.is_ordered()**

Queueing properties

- Some policies (**native** and **omp**) use queues to communicate pipeline stages.

- **Properties**:
  - **Queue size**: Buffer size of the queue.
  - **Mode**: *blocking* versus *lock-free*.

- **API**
  - **ex.set_queue_attributes(100, mode::blocking)**

Filter pattern

- A **filter** pattern discards (or keeps) the data items from a data stream based on the outcome of a predicate.
- This pattern can be used only as a stage of a **pipeline**.

Filter pattern

- A **filter** pattern discards (or keeps) the data items from a data stream based on the outcome of a predicate.
- This pattern can be used only as a stage of a **pipeline**.

- **Alternatives**:
  - **Keep**: Only data items satisfying the predicate are sent to the next stage.
  - **Discard**: Only data items **not satisfying** the predicate are sent to the next stage.

Filtering in

Print primes

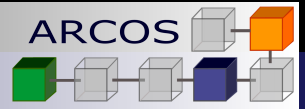
```
bool is_prime(int n);

template <typename Execution>
void print_primes(const Execution & ex, int n)
{
  grppi::pipeline(exec,
    [i=0,max=n]() mutable -> optional<int> {
      if (i<=n) return i++;
      else return {};
    },
    grppi::keep(is_prime),
    [](int x) { cout << x << "\n"; }
  );
}
```

Filtering out

Discard words

```
template <typename Execution>
void print_primes(const Execution & ex, std::istream & is)
{
  grppi::pipeline(exec,
    [& file ]()  -> optional<string> {
      string word;
      file >> word;
      if (! file ) { return {}; }
      else { return word; }
    },
    grppi::discard ([]( std::string w) { return w.length() < 4; },
     []( std::string w) { cout << x << "\n"; }
  );
}
```



Example

- Video frame processing for border detection with two filters.
  - Gaussian blur.
  - Sobel.

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- Using **pipeline** pattern:
  - S1: Frame reading.
  - S2: Gaussian blur (may apply **farm**).
  - S3: Sobel filter (may apply **farm**).
  - S4: Frame writing.

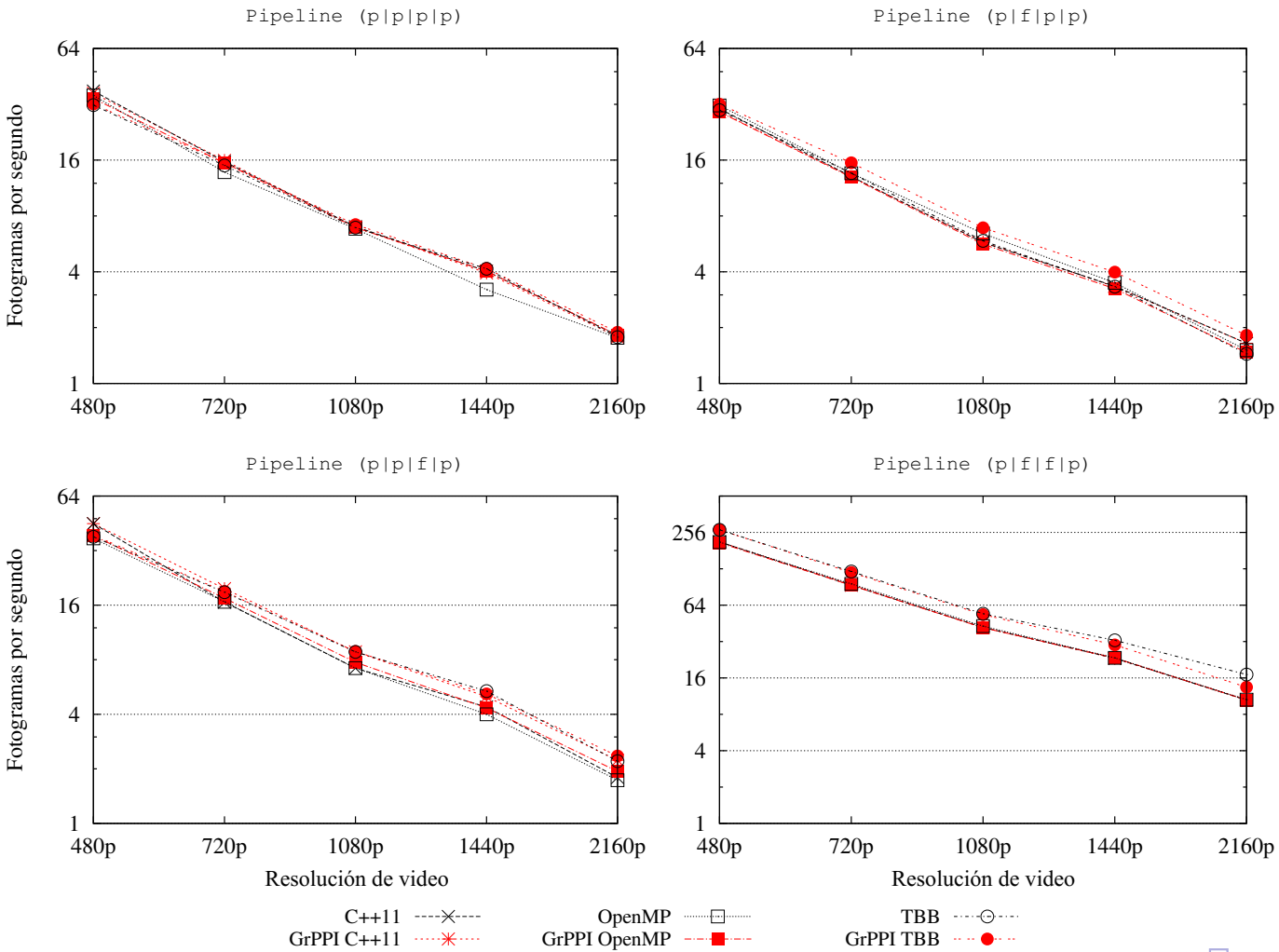
Example

- Video frame processing for border detection with two filters.
  - Gaussian blur.
  - Sobel.
- Using **pipeline** pattern:
  - S1: Frame reading.
  - S2: Gaussian blur (may apply **farm**).
  - S3: Sobel filter (may apply **farm**).
  - S4: Frame writing.
- **Approaches**:
  - Manual.
  - **GrPPI**.

Parallelization effort

Pipeline Composition	% LOC increase			
	C++ Threads	**OpenMP**	**Intel TBB**	**GrPPI**
(p | p | p | p)	+8.8 %	+13.0 %	+25.9 %	+1.8 %
(p | f | p | p)	+59.4 %	+62.6 %	+25.9 %	+3.1 %
(p | p | f | p)	+60.0 %	+63.9 %	+25.9 %	+3.1 %
(p | f | f | p)	+106.9 %	+109.4 %	+25.9 %	+4.4 %

Performance: frames per second

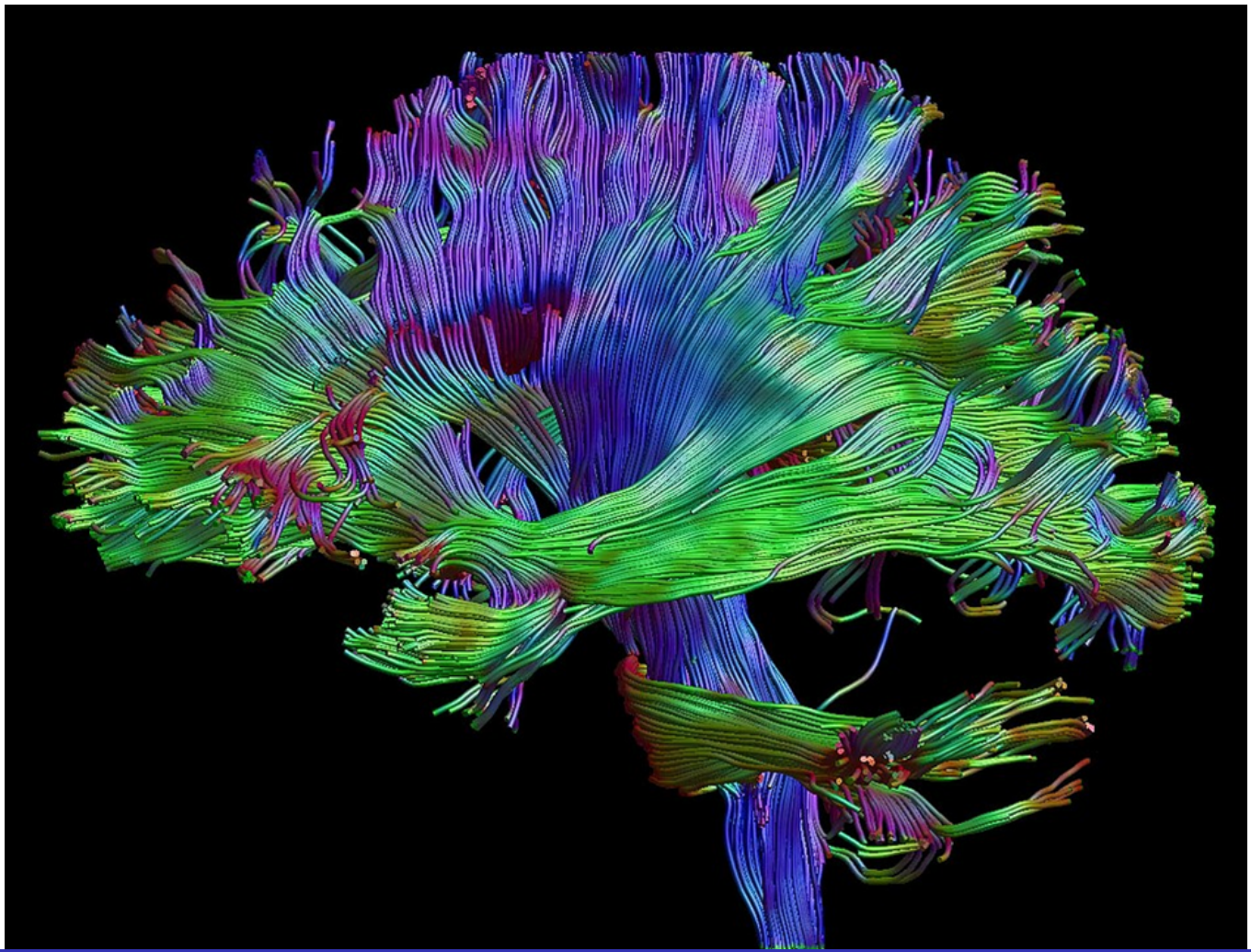


Brain MRI (Magnetic Resonance Imaging)

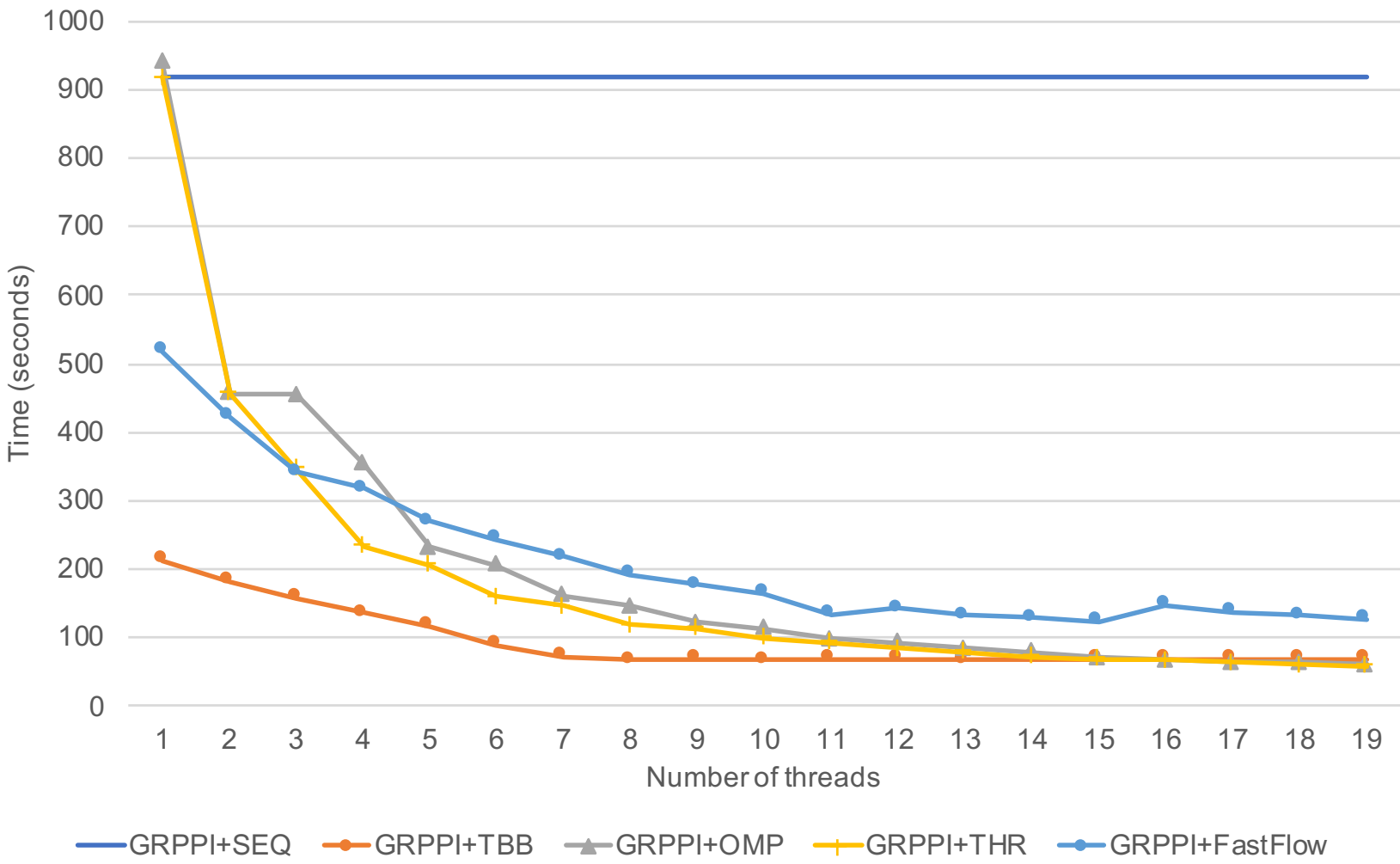
- Non intrusive method for getting internal anatomy.
- Huge amount of data generated.
- Applied to neuro-sciences.
  - Bipolar disorder.
  - Paranoia.
  - Schizophrenia.

- Identification of fibers and connectivity between areas in brain.

Fibbers in brain



MRI Evaluation



Summary

- A **unified programming model** for **sequential** and **parallel** modes.
- Multiple **back-ends** available: **sequential**, **OpenMP**, **TBB**, **native**, **FastFlow**.
- Current pattern set:
  - **Data**: **map**, **reduce**, **map/reduce**, **stencil**.
  - **Task**: **divide/conquer**.
  - **Streaming**: **pipeline** with nesting of **farm**, **filter**, **reduction**, **iteration**.
- **Low** programming effort.
- **Very low** performance overhead.

Further reading

- **A Generic Parallel Pattern Interface for Stream and Data Processing**. D. del Rio, M. F. Dolz, J. Fernández, J. D. García. Concurrency and Computation: Practice and Experience. 2017.

- **Exploring stream parallel patterns in distributed MPI environments**. Javier López-Gómez, Javier Fernández Muñoz, David del Rio Astorga, Manuel F. Dolz, J. Daniel Garcia. Parallel Computing. 84:24–36, 2019.
- **Challenging the abstraction penalty in parallel patterns libraries**. J. D. Garcia, D. del Rio, M. Aldinucci, F. Tordini, M. Danelutto, G. Mencagli, M. Torquati. Journal of Supercomputing, 21pp. 2019.
- **Paving the way towards high-level parallel pattern interfaces for data stream processing**. D. del Rio, M. F. Dolz, J. Fernandez, and J. D. Garcia. Future Generation Computer Systems 87:228-241. 2018
- **Supporting Advanced Patterns in GrPPI: a Generic Parallel Pattern Interface**. D. del rio, M. F. Dolz, J. Fernandez, and J. D. Garcia, Auto-DaSP 2017 (Euro-Par 2017).

Further reading

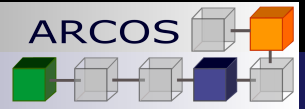
- **Towards Automatic Parallelization of Stream Processing Applications**. M. F. Dolz, D. del Rio, J. Fernandez, J. D. Garcia, and J. Carretero, IEEE Access, 6:39944-39961. 2018.
- **Finding parallel patterns through static analysis in C++ applications**. D. R. del Astorga, M. F. Dolz, L. M. Sanchez, J. D. Garcia, M. Danelutto, and M. Torquati, International Journal of High Performance Computing Applications, 2017.

GrPPI

https://github.com/arcosuc3m/grppi

Future work

- Additional backends:
  - Accelerator integration, distributed computing, ...



Future work

- Additional backends:
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- Next generation C++:
  - Concepts (reduce metaprogramming), modules.
  - Executors: parallel versus reactive models.
  - Ranges.

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  - Pattern catalog extension.
  - Minimal building blocks identification.

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- Additional backends:
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  - Ranges.
- More patterns and less patterns:
  - Simplified interface.
  - Pattern catalog extension.
  - Minimal building blocks identification.
- Pattern composition:
  - Pattern fusion.
  - Pattern transformation rules.
  - Multi-context approach for heterogenous computing.
  - Better support of NUMA and affinity.

The future

```
grppi::omp_execution omp;
grppi::cuda_execution cuda;

std::vector<int> v = get();
auto comp = v |
   grppi::map([](auto x) { return x*x; }) |
   grppi::reduce([](auto x, auto y) { return x+y; });
```

The future

```
grppi::omp_execution omp;
grppi::cuda_execution cuda;

std::vector<int> v = get();
auto comp = v |
   grppi::map([](auto x) { return x*x; }) |
   grppi::reduce([](auto x, auto y) { return x+y; });
comp >> grppi::on(omp);
```

The future

```
grppi::omp_execution omp;
grppi::cuda_execution cuda;

std::vector<int> v = get();
auto comp = v |
  grppi::map([](auto x) { return x*x; }) |
  grppi::reduce([](auto x, auto y) { return x+y; });
comp >> grppi::on(omp);

auto pipe = generator |
  ( grppi::seq([](const frame & f) { return filter(f); }) |
    grppi::farm(4, [](const frame & f) { return to_gray(f); })
    >> on(cuda)
  ) |
  frame_writer >> on(omp);
```

An introduction to **GrPPI**

Generic Reusable Parallel Patterns Interface

J. Daniel Garcia

ARCOS Group
University Carlos III of Madrid
Spain

November 2019