# Parallel Design Patterns-L08

Parallel Frameworks II

Course Organiser: Dr Nick Brown
nick.brown@ed.ac.uk
Bayes room 2.13

## Framework recap

- In the last lecture we considered the design of frameworks with some common HPC examples.
  - Focused around a specific aim and parallelism a secondary aim
  - These examples are commonly used on HPC systems

- Today we are going to look at some frameworks which are first and foremost there to abstract the parallelism
  - This is a much tougher area and no one framework has (yet) gained popularity in this area

- Today we are going to think about the implementation in a bit more detail

## Skeletons

- Capture the algorithmic form common to numerous applications
- A skeleton implements a parallel pattern
  - Taking care of the lower level, tricky and often uninteresting details such as communication, synchronisation and distribution
  - The programmer fleshes these out with their application logic
  - The programmer still needs to select the correct skeleton to use
- Are often integrated with higher level languages such as functional languages

*compile :: [Char] -> [Char]*

*compile = PIPE [ readfile, lex, parse, typeCheck, genCode, writefile ]*

*readfile, lex, parse, typeCheck, genCode, writefile :: [Char] -> [Char]*

## Examples skeletons

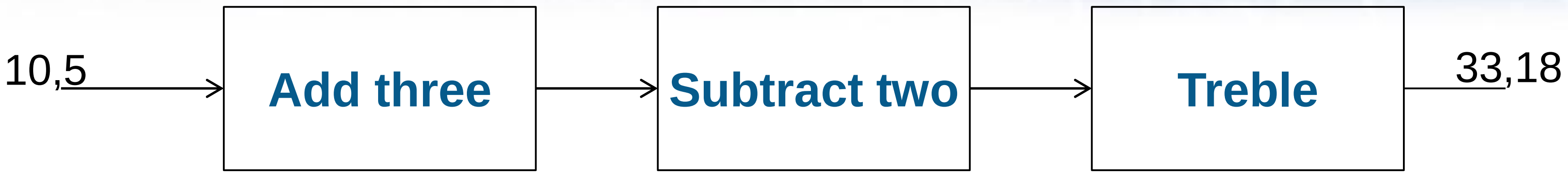
- **FARM** is also known as *master-worker* or *master-slave*.
- **PIPE** represents staged computation.
- **FOR** represents fixed iteration, where a task is executed a fixed number of times.
- **WHILE** represents conditional iteration, where a given skeleton is executed until a condition is met.
- **MAP** represents *split*, *execute*, *merge* computation. A task is divided into sub-tasks, sub-tasks are executed in parallel according to a given skeleton, and finally sub-task's results are merged to produce the original task's result.
- **D&C** represents divide and conquer parallelism.

## eSkel

- Developed by the School of Informatics
- The programmer writes C code which simply calls this as a library
- Uses MPI for underlying communications layer

http://homepages.inf.ed.ac.uk/mic/eSkel

# eSkel example pipeline



```
#include "eSkel.h"
eSkel_atom_t* addThree(eSkel_atom_t * in){
    int * data=(int*) in->data;
    data+=3;
    return in;
}
eSkel_atom_t* minusTwo(eSkel_atom_t * in){
    int * data=(int*) in->data;
    data-=2;
    return in;
}
eSkel_atom_t* treble(eSkel_atom_t * in){
    int * data=(int*) in->data;
    data*=3;
    return in;
}
```

```
int main() {
  int inputs[2]={5,10}, results[2];
  eSkel_atom_t* (*stages[3])(eSkel_atom_t*);

  stages[0]=addThree;
  stages[1]=minusTwo;
  stages[2]=treble;

  pipeline1for1(3, stages, …, inputs, ……,
                              results, ……);
}
```

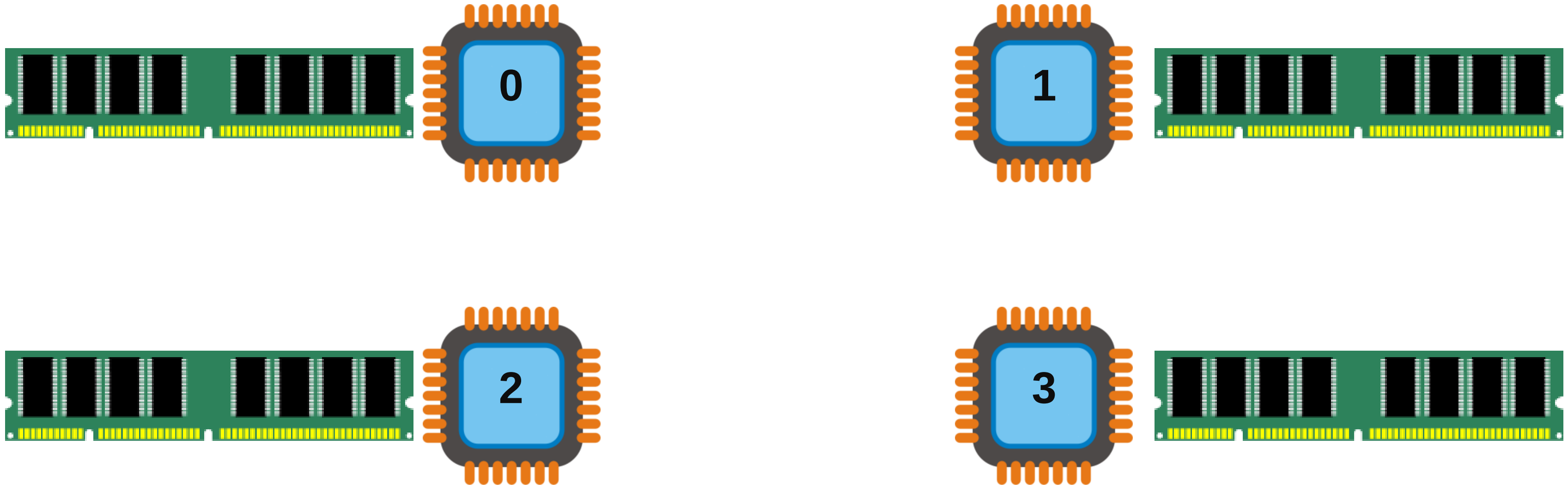
## Comments about skeletons

- A very interesting area of research
  - And one the school of informatics is involved in (*http://homepages.inf.ed.ac.uk/mic/Skeletons/index.html*)
  - A number of existing frameworks have been developed which implement similar skeletons
- Has yet to gain wide acceptance in the field of HPC
  - Issue of transparency – what is the underlying runtime actually doing in my skeleton, is it performant or scalable?
  - Requires not only a reengineering of codes but also a mind set change on behalf of the programmers (many of which are still using Fortran!)

- Aspects of these technologies can often find their way into more mainstream languages
  - Arguably Hadoop is a MapReduce skeleton

## UPC++

- UPC is an extension to C that provides the user with a Partitioned Global Address Space memory model
  - The addition of keywords into C that the UPC compiler then processes



  - Whilst this allowed the user to use an existing language, it still required an additional compiler to be installed and was inflexible for adding additional functionality

## UPC++

- UPC is an extension to C that provides the user with a Partitioned Global Address Space memory model
  – The addition of keywords into C that the UPC compiler then processes
  – Required additional compiler be installed and inflexible for adding functionality

```
shared int y[THREADS]; /* one y on each thread */
shared int a[100][THREADS]; /* one a[100] on each thread*/
shared int b[100]; /* Distributed across threads */
shared int x; /* One x in entire system */

shared int *p; /* a local item which points elsewhere */

p=upc_alloc(200);
```

- Re-engineered UPC to work with C++ and provided as a library
  – Via objects and templates

```
shared_array<unsigned long> A(100);

shared_array<int> b;
b.init(200);

global_ptr<int> ptr;
```

## UPC++

- Shows some promise but yet to gain acceptance
  - HPC programmer encouraged to use C++, might be able to wrap it
  - Have to trust that the library will do the right thing
- This idea of templates with C++ is a nice abstraction
  - Especially because additional policy could be injected
  - **`shared_array<int, even_distribution> b;`**
- The library should be made accessible so that other HPC people can go in and create specialisations of these things
  - That might abstract the partitioning and distribution of data further which UPC++ currently lacks

## Java Concurrency

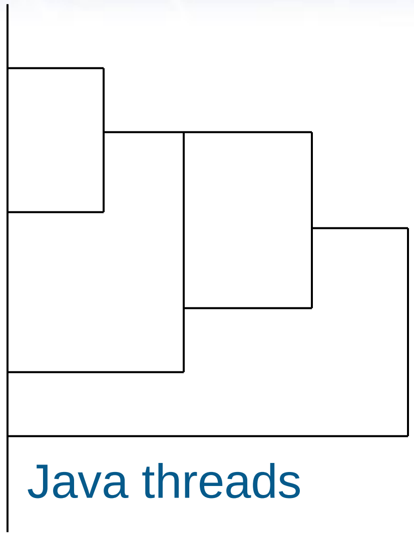
- As a framework Java carries a lot of deprecated baggage around to maintain backwards compatibility

- There is a package in Java called java.util.concurrent
  - Available since Java 1.5, so now very established
- An integral part of java, but implemented as a package
  - In other words, someone else could have written such a package
- Java has support for threads as part of the language, along with some basic mechanisms to support synchronisation between threads such as the **`synchronized`** keyword

- Whilst Java itself might not be popular in the HPC field, how Java handles these aspects finds itself into other frameworks

# Recap from Threaded Programming

- Parallelism versus concurrency?
- Java threads work on shared memory model
  - with the option to declare data to be private to a thread
- A thread is an object
- Threads are spawned in various ways:
  - Extending the **java.lang.**Thread class
  - Implementing the **java.lang.**Runnable interface
  - Using an ExecutorService and implementing the **java.lang.**Runnable interface
  - Using an ExecutorService and implementing the **java.util.concurrent.**Callable interface



*Core language*

*java.util.concurrent package*

## Spawning Threads

- Extending the **java.lang.**Thread class
  - Extend the class java.lang.Thread
  - Override the run method
  - Start a Thread
- Implementing the **java.lang.**Runnable interface
  - Implement the java.lang.Runnable interface
  - Create a new instance of type MyClass
  - Create a new Thread object wrapping the runnable

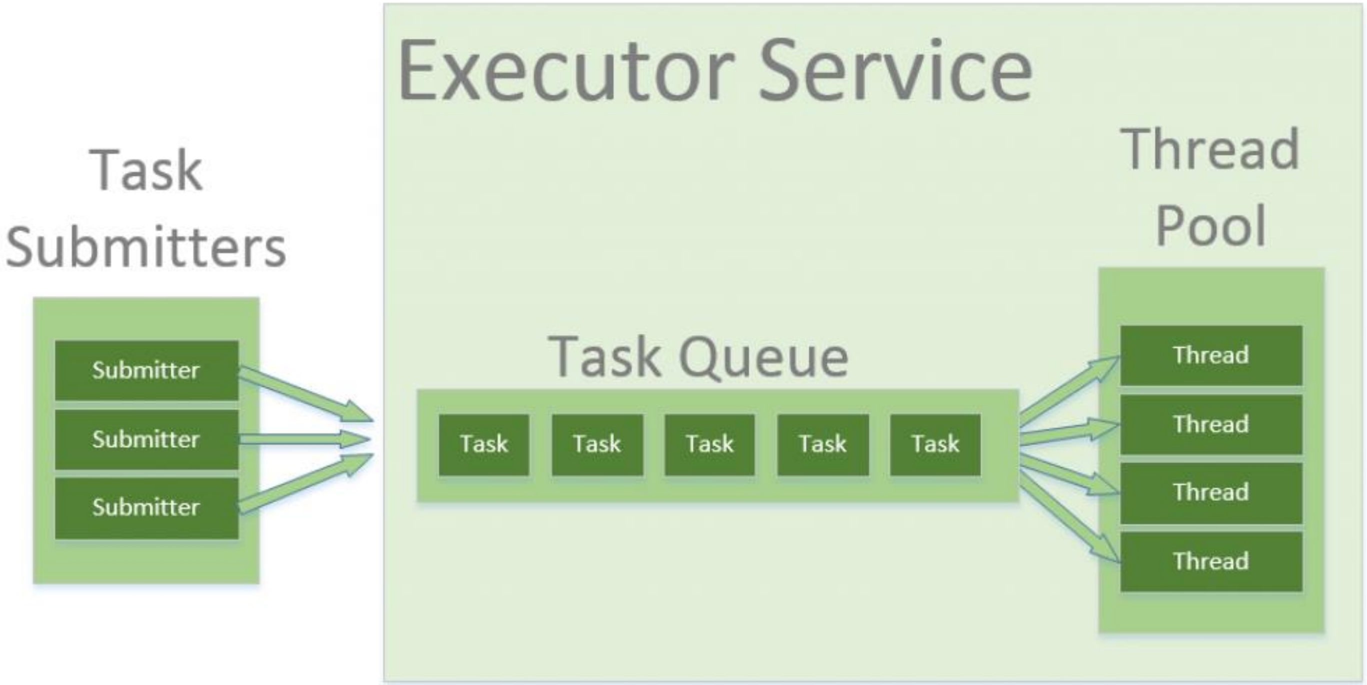
*Core language*

- ExecutorService
  - with java.lang.Runnable
    - **`run()`** method does not return values
  - with java.util.concurrent.Callable
    - more flexible

*java.util.concurrent package*

## Java Interface ExecutorService

- **ExecutorService** interface
  - Provides a way of decoupling task submission from the mechanics of how each task will be run, including details of thread use, scheduling,



- The submit method returns a Future that can be used to manage the task (e.g. cancel execution, wait for completion).

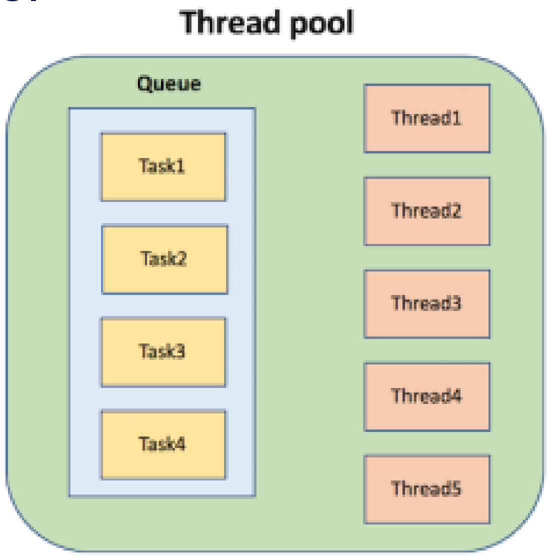
## Java Future

- **Future** interface
  - `public interface **Future**<V>`
    - `Future f=my_executor.submit(new MyClass());`

- Defined in java.util.concurrent
  - Represents the result of an asynchronous computation
  - Objects conforming to this interface are passed around a program instead of the values themselves, thereby removing the need to wait for an asynchronous computation to complete until the last minute
- Methods are provided to interrogate the progress
  - f.isDone() to test for completion
  - f.isCancelled() to test for cancelation
- Get will retrieve the result (optional max time) and cancel will cancel the request

## ScheduledThreadPoolExecutor

- Implements the ExecutorService interface
  - Instantiated with the number of threads in the pool
- Useful for resource management
  - Typically you want to map tasks to threads rather than create a new thread for each task
  - If done wrongly this can be quite a performance bottleneck
  - The API determines the best way of doing this, best way of queuing up tasks



- Useful for resource management and performance
  - Typically you want to map tasks to threads rather than create a new thread for each task
  - If done wrongly this can be quite a performance bottleneck
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## These communication frameworks

- We have seen some examples of the parallelism being abstracted from the programmer
  - Just a few examples of very many in this field
  - None of these have (yet) reached any mainstream success in HPC

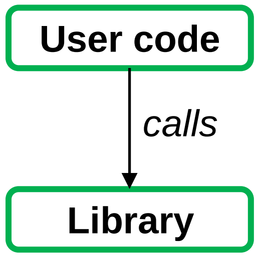
- A variety of reasons why we still use C/Fortran with MPI or OpenMP
  - Abstraction makes too many assumptions causing poor performance
  - Limited maturity
  - Limited flexibility
  - User reticence for learning new technologies

## Common ways of code reuse

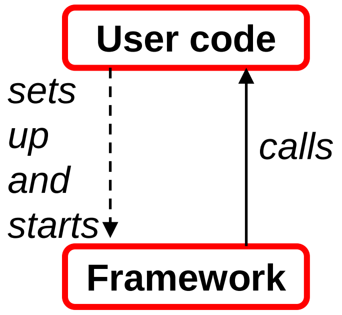
Loosely integrated

Heavily integrated

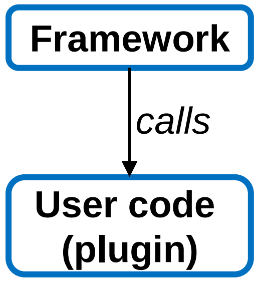
1. Calling functions in a library via an API
   - Entirety of functionality is pre-existing
   - Either has some side effect (such as writing a file/sending a message) or returns data that you then work with



2. Injecting own code into the framework
   - In C or Fortran via function pointer args to API
   - Sometimes known as a callback



3. Oriented around user provided plugins
   - Structured user defined behaviour
   - Main entry point is the framework and it calls the user plugins as appropriate



## 1 - Calling functions in a library via an API

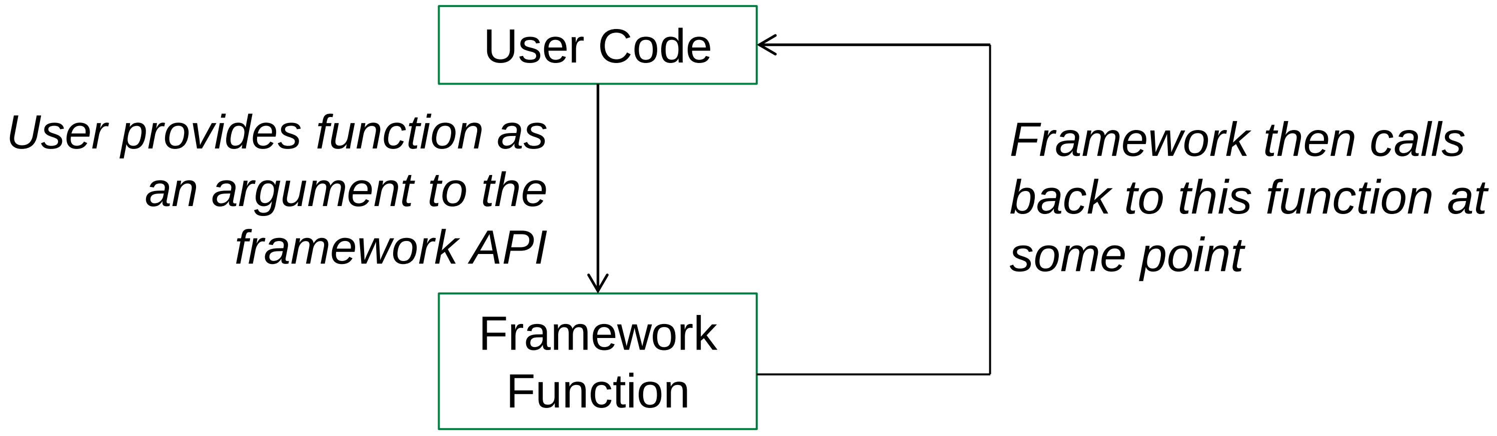
- A specific API call should do one think and do it well
  - Avoid magic arguments or mode bits
- APIs should be as small as possible but no smaller
- The API should be separate from the implementation
- Names and consistency matter
  - Self explanatory
  - Consistency in your API and with the community
- Documentation
  - Inline documentation
  - Examples
- Consider error handling

Based on http://www.cs.bc.edu/~muller/teaching/cs102/s06/lib/pdf/api-design.pdf

## API external and internal data types

- APIs can often require structured data as arguments
  - As a C structure or Fortran derived type
- It can be quite common to differentiate between the data types in your external interface and those used internally
  - Avoids exposing the internals of your framework implementation to the user (can avoid miss use.)
  - Can provide increased flexibility, where your framework implementation can change independently of the user code that calls it
- However a “glue layer” is required to convert from the external data types to internal data types
  - Can be a source of bugs and increased complexity
  - Might have a performance impact

## 2 - Injecting code into the framework


User Code
User provides function as an argument to the framework API
Framework Function
Framework then calls back to this function at some point

- User function can be either mandatory or optional, overriding some sensible default provided by the framework
- Can be a good way of providing complex functionality to the framework
  – The alternative being a very complex API
- In C and Fortran implemented via function pointers

## 3 - User provided plugins

- A plugin performs some high level behaviour
  - Often a collection of many functions
  - Often some sort of description about the module
- Independent of each other
- The framework defines a standard plugin template
  - Which each user provided plugin must follow
- The framework provides ways in which these can be managed
- Any inter-plugin communication follows a standard, organised, approach
- Plugins either present during compilation or plugged in at runtime

## MONC

- A cloud resolution model employed by UK weather and climate communities
  - Space is decomposed via the geometric decomposition pattern
  - Time progresses in time steps
- A key requirement was that scientists could easily add, remove or modify functionality
  - Modelling of specific systems requires code changes
  - But how to do this in a way that avoided poor code polluting the rest of the model?
- Architected as a set of components (plugins)
  - With optional call backs for initialisation, timestepping and finalisation

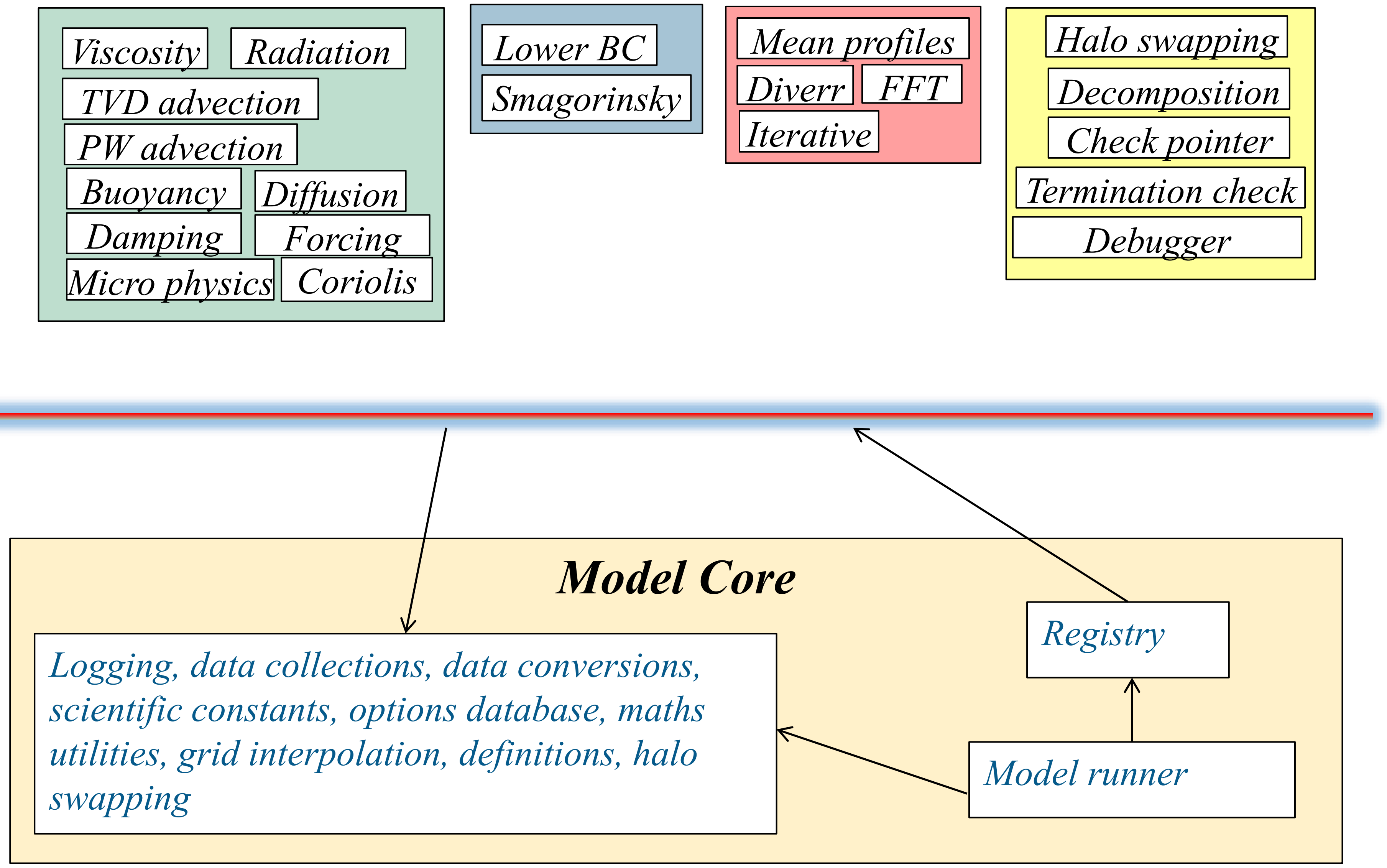
## MONC plugin template

```
type(component_descriptor_type) function test_get_descriptor()
    test_get_descriptor%name="test_component"
    test_get_descriptor%version=0.1
    test_get_descriptor%initialisation=>initialisation_callback
    test_get_descriptor%timestep=>timestep_callback
end function test_get_descriptor
```

```
subroutine initialisation_callback(current_state)
    type(model_state_type), target, intent(inout) :: current_state
    ………………
end subroutine initialisation_callback
```

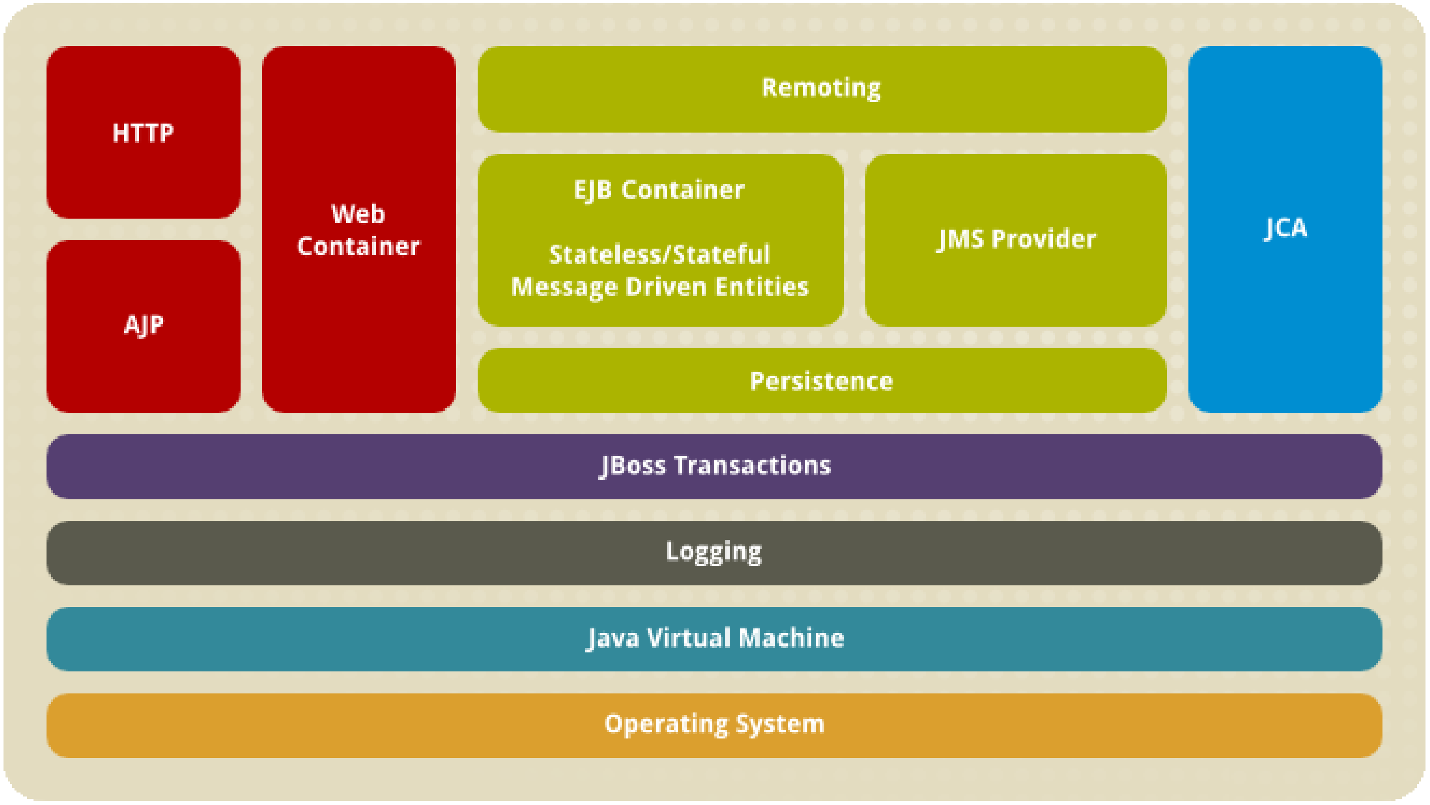
```
subroutine timestep_callback(current_state)
    type(model_state_type), target, intent(inout) :: current_state
    ………………
end subroutine timestep_callback
```

# MONC Components



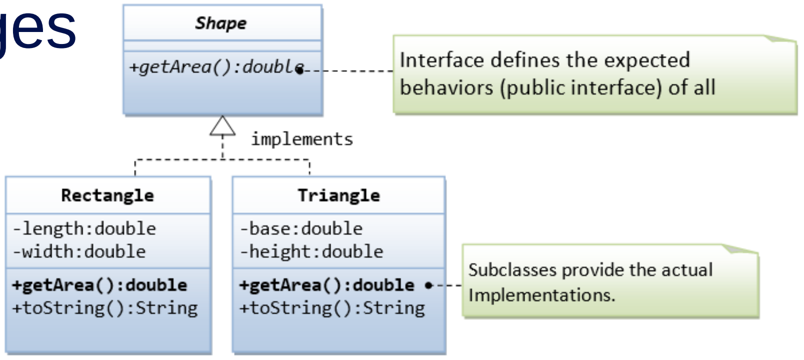
## JBoss (or Wildfly)

- An application server that allows one to easily publish J2E web applications
  - User applications are packaged into a predefined format and deployed. As well as the code themselves they also contain configuration files



# So how do we write a framework?

- In C++, Java or other OO languages there are various techniques for generic programming
  - Most important here is inheritance
  - Extend an existing class or implement an interface



- In C, Fortran (which tend to fit more closely with MPI and OpenMP), a useful idea is that of function pointers
  - Pass a function to a function, instead of just variables
  - As a very basic example, you could have a function *invoke* which takes as arguments the integers *a* and *b,* and a mathematical function to perform on these
  - C variants (C++, Objective C) and “modern” Fortran (2003 onwards) also have OO features

## Function Pointers in C

- To declare the general function
  - `int invoke(int (*fn_pointer)(int, int), int a, int b);`
- To declare the function that will be run
  - `int add_fn(int a, int b) {…}`
  - `int subtract_fn(int a, int b) {…}`
- To call the function
  - `int result = invoke(add_fn, 2, 8);`
  - `int result2 = invoke(subtract_fn, 2, 8);`

## Example in C

```
#include <stdio.h>

int add_fn(int a, int b) {
  return a+b;
}

int subtract_fn(int a, int b) {
  return a-b;
}

int invoke(int (*fn_pointer)(int, int), int a, int b) {
  return (*fn_pointer)(a, b);
}

int main() {
  int result = invoke(add_fn, 2, 8);
  int result2 = invoke(subtract_fn, 2, 8);
  printf("%d and %d\n", result, result2);
  return 0;
}
```

# Generic arguments in C

- What about supporting both:
  - `int add_fn(int a, int b) {…}`
  - `int abplusc_fn(double a, double b, double c) {…}`

```
#include <stdarg.h>

int add_fn(va_list valist) {
  return va_arg(valist, int)+va_arg(valist, int);
}

int abplusc_fn(va_list valist) {
 return (int) (va_arg(valist, double) * va_arg(valist, double)) + va_arg(valist, double);
}

int invoke(int (*fn_pointer)(va_list), ...) {
  va_list valist;
  va_start(valist, fn_pointer);
  int result = fn_pointer(valist);
  va_end(valist);
  return result;
}

int main() {
  int result = invoke(add_fn, 2, 8);
  int result2 = invoke(abplusc_fn, 2.3, 8.5, 7.4);
  return 0;
}
```

## Function Pointer in Fortran

- To define the "function pointer"

  -
    ```
    interface
      integer function fn_pointer(a,b)
        integer, intent(in) :: a, b
      end function fn_pointer
    end interface
    ```
- To declare the general procedure

  -
    ```
    subroutine invoke(provided_function, x, n)
      integer, intent(in) :: n, x
      procedure(fn_pointer) :: provided_function
    end subroutine invoke
    ```
- To call the procedure
  - `call invoke(add_fn, n, x)`
  - `call invoke(subtract_fn, n, x)`

# Example in Fortran

```
module b
  implicit none

  interface
    integer function fn_pointer(a, b)
      integer, intent(in) :: a, b
    end function fn_pointer
  end interface
contains
  integer function add_fn(a, b)
    integer, intent(in) :: a, b
    add_fn =a+b
  end function fn1

  integer function subtract_fn(a ,b)
    integer, intent(in) :: a, b
    subtract_fn =a-b
  end function fn2

  integer function & invoke(provided_function, a, b)
    procedure(fn_pointer) :: provided_function
    integer, intent(in) :: a, b

    invoke=provided_function(a, b)
    end function invoke
end module b
```

```
program a
  use b
  implicit none

  integer :: result, result2
  result =invoke(add_fn, 2, 8)
  result2=invoke(subtract_fn, 2, 8)
  print *, result, result2
end program a
```

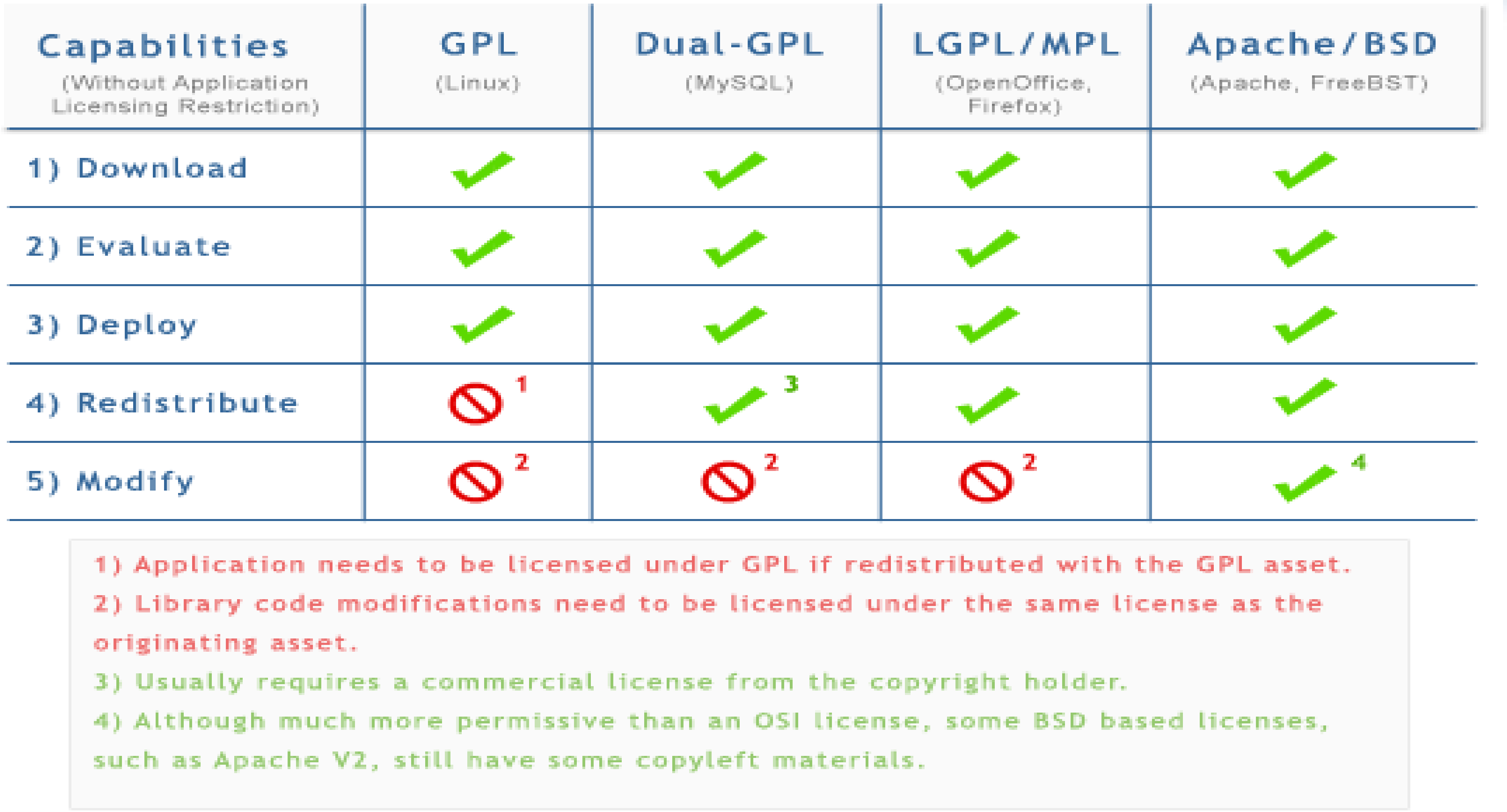
## Compiler Support for Fortran 2003

- The example on the previous slides is valid Fortran 2003
- Not all compilers are fully compliant
  - With different levels of maturity

- Current Support for Procedure Pointers
  - Derived partially from *Fortran 2003 status,* in Fortran Wiki http://fortranwiki.org/fortran/show/Fortran+2003+status (Accessed 2015-01-16)

| Compiler | Support |
|---|---|
| Absoft | Y |
| Cray | Y |
| GNU (gfortran) | Y |
| g95 | Y |
| HP | Y |
| IBM | Y |
| Intel | Y |
| NAG | Y |
| Oracle | Y |
| Pathscale | N |
| PGI | Y |

# Licencing



| Capabilities (Without Application Licensing Restriction) | GPL (Linux) | Dual-GPL (MySQL) | LGPL/MPL (OpenOffice, Firefox) | Apache/BSD (Apache, FreeBST) |
|---|---|---|---|---|
| 1) Download | ✓ | ✓ | ✓ | ✓ |
| 2) Evaluate | ✓ | ✓ | ✓ | ✓ |
| 3) Deploy | ✓ | ✓ | ✓ | ✓ |
| 4) Redistribute | 🚫 [1] | ✓ [3] | ✓ | ✓ |
| 5) Modify | 🚫 [2] | 🚫 [2] | 🚫 [2] | ✓ [4] |

1) Application needs to be licensed under GPL if redistributed with the GPL asset.
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3) Usually requires a commercial license from the copyright holder.
4) Although much more permissive than an OSI license, some BSD based licenses, such as Apache V2, still have some copyleft materials.

http://programmers.stackexchange.com/questions/105344/is-there-a-chart-for-helping-me-decide-between-open-source-licenses

Lots more information at http://choosealicense.com/licenses/

## Summary

- Most languages provide mechanisms for writing generic code
  - These mechanisms can be used to implement parallelism in a way that is independent of the application
  - Where is my split between mechanism and policy, and what does this interface look like (i.e. is it powerful enough)?
- With clean interfaces, you can write “good” code first, and then optimise for performance
- A variety of design decisions can impact whether a framework is generally useful or not
  - And additional non-technical issues too