[1]GIG-Pattern

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Abstract

This paper proposes a pattern called GIG, a generic interface graph which deals with definition and control of processes taking into account some specific requirements of simplicity, easiness of definition from algorithmic natural language and flexibility in the granularity of defined processes. The pattern is intended to help the design and reuse of programs.

1. Introduction

The use of workflow technology helps the development of more flexible and versatile computation strategies. So, workflow management systems are a relevant support for large class of business applications, and many workflow models as well as commercial products are currently available [8]. While the large availability of tools facilitates the development and the fulfillment of customer requirements, workflow applications still require simple, generic and adaptive solutions for the complex task of rapidly producing effective applications, especially when complex domains are involved.

The GIG pattern was developed after we noticed that many numerical algorithms showed the very same organizing structure when trying to achieve process reuse and flexibility for the adaptation to new strategies. Such an organizing structure in turn allowed for an abstraction, which resulted in the GIG, a generic interface graph. GIG-pattern is not self implementable. However, as it will be seen, it is possible to devise frameworks to use the GIG pattern in order to implement different processes in a very flexible and automatic way.

The GIG-pattern describes an abstract workflow solution, whose purpose is to provide expressiveness and adaptability through a simplified workflow programming, control and use [8]. Other GIG motivation is to maintain predefined algorithmic structure, which means that the translation from algorithmic language representation of the processes into a computer representation must be as direct as possible. This is important because, the achievement of similarity between the way the programmer has its algorithmic code organized and the implementation of it, can bring simplification in further required changes. Also, sometimes, developers need solutions, which does not make restrictions on the scale of the process, that is, which need a mixture of small-scale processes (that execute within applications) and large-scale processes (that execute on top of applications), usually this happens when designers are also the programmers.

As a workflow pattern, GIG provides for the separation of process logic from task logic, which is embedded in individual user applications, allowing the two to be independently modified and the same logic to be reused in different cases. The GIG-pattern considers features related to run-time control functions [7], which manage the workflow processes and sequence the various activities.

This work was devised from the experience obtained during the implementation of several simulators in the Finite Element Method (FEM) context [5]. FEM is a way of implementing an approximate mathematical theory for a physical behaviour. Researchers of the Mechanical Engineering Department – UFPE- Brazil found the need to organize their code in a way that was

easier to adapt to new strategies and also to allow process reuse. So they designed and implemented the GIG, a generic interface graph, which provides a process to achieve the mentioned advantages. In this paper the GIG is presented as a pattern.

The pattern's description is organized in the following way. In section 2 the pattern name is identified. Section 3, details the context in which the pattern solution applies. Section 4 presents the design challenge through a question. Section 5 shows pattern forces, that is, the patterns design trade-offs, what pulls the problem in different directions, towards different solutions. Section 6 explains how to solve the problem. Section 7 describes the pattern implementation. Section 8 presents some variants that can extend the pattern. Section 9 presents a simple example of use, in order to clarify the pattern use and section 10 presents a more complex one in the FEM simulators context. Section 11 details the resulting context, telling which forces the pattern resolves and which forces remains unresolved by the pattern. Section 11 presents related patterns. Finally, section 12 talks about known uses.

2. Name: GIG-Pattern, Generic Interface Graph for process control.

3. Context

Domain specific users, like scientists and engineers, usually program in a procedural style. The explanation for that, in spite of the force of tradition, may be the following. Complex numerical systems usually make use of many different pre-built auxiliary packages (like numerical integrators, solvers for non-linear and linear systems of algebraic equations, and so on) and have their procedures described in algorithmic language. So, the majority of the work is related to making the modules compatible in a monolithic architecture, which resembles the structure of the algorithm. This is a strong force that drives those users towards the procedural style.

During the development of a software system, those developers need functions that help them to organize their logical processes and their involved tasks, in a way that makes it easier its future alteration for adapting to new solutions and for the reuse of old software components, avoiding heavy reprogramming. We have repeatedly noticed that many numerical algorithms showed the very same organizing structure. Such an organizing structure comes from the procedural style of the algorithm representation and can be identified to be a directed acyclic graph. This observation can lead to the definition of a workflow pattern, like the one we describe in this work, that is, the GIG.

4. Problem

How to guarantee simplicity in the separation of process logic from task logic, during the development of complex systems, while maintaining solution independence, reuse of processes and the predefined algorithmic structure?

5. Forces

With respect to the defined context, there are different forces, which lead to different solutions like: maintain predefined algorithmic structure; simplicity in the process definition; support for different levels of granularity on the defined processes; domain independence; dynamic change of workflow processes; reduction of error occurrences in the coupling of processes; reuse of processes; parallelism and processes synchronization; workflow execution performance; explore existing expertise of domains of knowledge.The following discussion analysis some of these forces, in order to identify how they are pulling against each other. GIG tries to resolve some opposing forces in the workflow definition context.

When trying to maintain the predefined algorithmic structure, the definition of some subprocess could arise parts of code that are not easily changeable, because are monolithically defined as a block

of code. On the other hand, refined levels on process partioning can provide a process definition at statement level, eliminating existing abstractions (like blocks or modules). Domain independence and dynamic change of process requires abstractions like polymorphism and encapsulation, which are not present in a procedural style (the predefined algorithmic structure).

The guarantee of simplicity in process definition can be one way to avoid errors and stimulate the pattern use. Some opposing forces to simple process definition are: the guarantee of domain independence, which makes more complex the process definition; changing process at run-time gives the programmer the complex task of making a suitable partitining of code and data; also, to allow the definition of processes parallelism and synchronisation the programmer has to deal with extra levels of complexity. The simplification can be compromised when parallelism is required for increasing performance.

On one hand, it is important to simplify the process definition, however, on the other hand it is also important to support the flexibillity of having different levels of granularity for the process partitioning, since users can access and control lower process levels. But, the definition of refined levels of process can arouses loose of abstraction, reducing simplicity.

The reuse of already developed and tested processes helps in the simplification of process definition, like the possibility to reuse entire solutions. On the other hand the reuse of processes can also reduces the simplicity due to the need for extensions of classes or configuration.

Process reuse improves reduction of errors once pre-tested software is incorporated. Refined levels of granularity, in process definition, provide higher level of tangibility in the number of processes to be controlled, increasing the reuse of processes. The guarantee of domain independence also increases the number of reusable process.

Domain independence, avoiding non-monolithic solutions, makes possible the application of the workflow solution to different applications, improving its reuse. However, in these cases the existing expertise of a knowledge domain cannot be appropriately explored to improve the solution. Maintaining predefined algorithmic structure, do not help domain independence because procedural style does not provides abstractions such as encapsulation. Also, synchronization and parallelism improve in one-way domain independent application supporting the required functionality to existing applications, but difficult its implementation, requiring more levels of complexity.
The dynamic change of workflow processes improves the solution power, however, gives the programmer the responsibility and the complex task of making a suitable division of code and data, for further exchanging be pertinent. The reuse of process is fundamental when the user has to change an existing one by another one, which is already tested and classified. Maintaining the pre-defined algorithmic structure does not help domain independence because it does not provides, for example, encapsulation. Synchronization and parallelism improve in one-way the power of the dynamic change of process (identifying which process are independent or the other of the dependence). On the other hand this can arises more complexity in the changing of processes.
Parallelism and processes synchronization are very relevant to allow system optimization and higher levels of control. However these also makes the system more complex. The refined levels of granularity, in process definition, can allow a more precise level of parallelism definition. The dynamic change of workflow and the reuse of process increase the synchronization power, in process exchanging.

On one hand, maintaining the predefined algorithmic structure can sometimes improve performance due to the direct application of some available optimised code; parallelism also improves performance, since allows simultaneous execution of process. On the other hand, simplicity on process definition can decreases the performance, when it eliminates, for example, the possibility of parallelism definition. The guarantee of domain independences can also decrease performance once the existing expertise cannot be appropriately explored. Other forces which compromises the performance, due to the need of extra verification and controls, are: refinement level of the granularity

of process definition; dynamic process exchange requires more controls; control of errors, reuse of process reduces the performance, synchronization.

6. Solution

GIG can be described as a workflow solution [7]. GIG follows the object-oriented style for modelling and programming. For purposes of simplicity of use and easy correctness verification, GIG implements a restricted direct acyclic graph (DAG) [5].

6.1 Participants (Structure)

The GIG structure is presented in the UML diagram below (Figure 1).

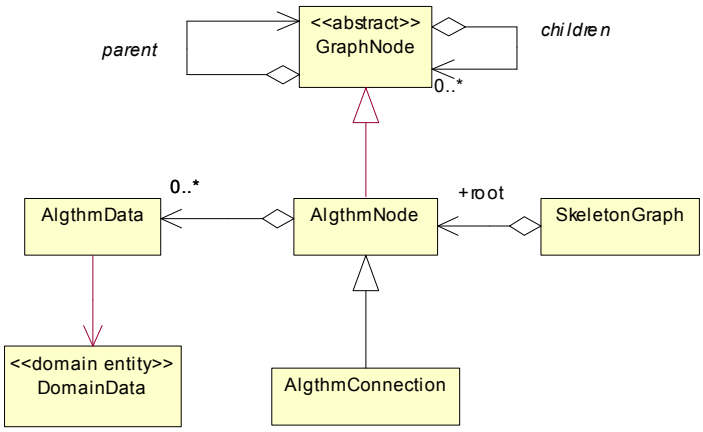


Figure 1. Participants of the GIG-pattern

The GIG pattern is composed of the following participants:

- *GraphNode*: it is an abstract class that implements low level operations related to the interoperability between workflow nodes.
- *SkeletonGraph*: it has a reference to the driver of an algorithm graph and encapsulates tools for performing some graph operations.
- *AlgthmNode*: represents the procedure (algorithm) of each workflow node. It is used as a base class for all algorithm classes of the application.
- *AlgthmData*: represents a data type to be used by an *AlgthmNode.* It is used as a base class for all algorithm data classes of the application.
- *DomainData*: represents the whole set of types related to the problem domain data
- *AlgthmConnection*: it is an *AlgthmNode*, which references an algorithm component that was not connected to the graph. This class responsibility is to fetch, and build (like a proxy [10]) the related algorithm and replaces itself with the fetched algorithm. In this way several software components represented by *SkeletonGraph*s can be assembled producing a complex software system.

6.2 Collaborations

6.3 We can identify the following collaborations between GIG participants:

- *GraphNode* encapsulates the responsibility of providing access to other *GraphNodes*, which are its children.

- *AlgthmNode* executes the associated process with the help of other software components represented by its children, through calls inserted in its process code. It relies on *GraphNode* to have access to its children *AlgthmNodes*
- *AlgthmData* provides access to workflow data. *AlgthmNode* communicates with *AlgthmData* to have access to its data.
- *AlgthmConnection* provides the dynamic connection for *AlgthmNodes*. The way objects of this class interact with its *SkeletonGraph* or its parents *AlgthmNodes* depends on the implementation. The important thing is that it represents the point where a driver node of a software component will be plugged in. It also contains the necessary information about the new *AlgthmNode*.

We can summarize the main part of GIG-pattern interaction, through the UML sequence diagram of Figure 2.The GIG driver, an object of *SkeletonGraph* class, creates the GIG root that is an instance of *AlgthmNode* class. When the *SkeletonGraph* requests the root to build the GIG, it instantiates each child and asks them to build its sub-graphs recursively. After the graph building the driver waits for requests for GIG execution, GIG reprogramming, and for other graph manipulation functionalities.

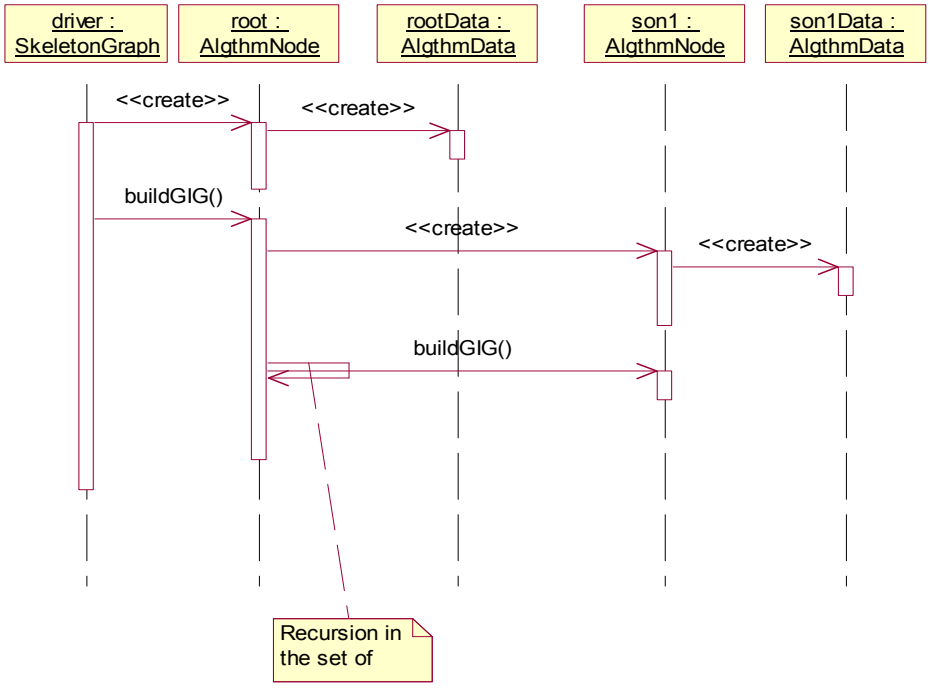


Figure 2. Sequence diagram for GIG building

7. Implementation

There are some implementation issues associated with the GIG participants, described previously, who need some extra explanation. Other important details about implementation are related to the design steps to be followed by the user for applying the GIG-pattern to a new application. In section 9, and 10 this steps are exemplified.

7.1 Implementation Issues

The *DomainData* is implemented by a set of subclasses of the *AlgthmData*. The subclasses of *AlgthmData* describe the specific domain treated in the problem. An example of the partition of the domain in different levels can be seen in the section 10.
The *AlgthmData* and *AlgthmNode* objects must be materialised for the workflow they are serving. The materialization activities, of *AlgthmData* and *AlgthmNode* objects, can be delegated to object factories that are responsible to access the data repository and instantiate the objects, these object factories can have object pools to reuse objects, see section 12 for details about the patterns that can be applied.

The *AlgthmNode* subclasses need to cast the *AlgthmData* objects, associated with each node, to the primitive type.

As was shown each *AlgthmNode* object must have a reference for all its children and data. This reference can be hard coded in *AlgthmNode* subclass, or in a file, or can be handled by another class, which has the responsibility to relate each *AlgthmNode* with its children. An example of such a class is *DataAlgthmServer* use in example 9. In this case each *AlgthmNode* can ask to the *DataAlgthmServer* for its children and data or the *DataAlgthmServer* can be active and responsible to build the GIG.

7.2 Design Steps

The following design steps describe which actions the user needs to perform to apply the GIG-pattern to a problem:

1) Starting from an algorithm in natural language the procedure is first divided into different algorithm components (algorithm nodes) and then it is organized in the form of a graph.
2) The division of the algorithm into several algorithm components induces a decomposition of the domain data in order to provide them with an appropriate distribution of access to the data. The result of this process gives the *AlgthmData* set.
3) Each *AlgthmNode*, that is an algorithm component, places calls to its children nodes, which implement processes inside the whole process. The logic is defined inside each *AlgthmNode* subclass and it references the execution of a child algorithm, independently of the routine that is in that child.
4) Each *AlgthmNode* is related to a set of *AlgthmData*, which may be shared with other nodes.
5) The driver of the whole process is identified.

8. Variants

(i) The *ObjectType* pattern [9] can be used to enhance the performance of *AlgthmNode*, producing independence between the software component and its data components. This is important in situations where the same software component is to be used in different situations and with different pieces of data. The class diagram is like the one in Figure 3. With this extension *AlgthmType* provides the *AlgthmNode* the needed functionality independently of AlgthmData. The relationship between the *AlgthmData* and *DataType* can be done at run time. This extension does not affect the already described interactions of *AlgthmNode* and *AlgthmData* with theother participants .

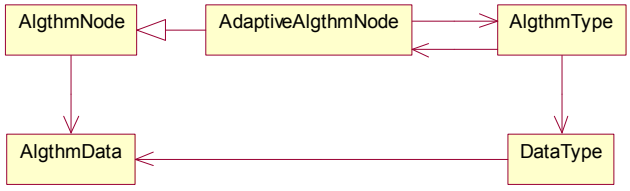


Figure 3. Class diagram for a variant of AlgthmNode

(ii) Hierarchical levels of procedures can be defined, helping in the software management. An application of this extension can be seen in section 10, where three levels of *SkeletonGraphs* were defined. For each one of those levels one may define specific functionalities for all their respective *AlgthmNodes* and *AlgthmData*. Also, at the level of the functionalities of the *SkeletonGraphs* objects specific tools can be defined. These extensions can be oriented for the applications being considered.

(iii) It can be extended to deals with the definition/execution of processes running in a distributed environment. We will not go into further details because this is still under development.

9. First Example of Usage

To exemplify and make clear the use of the GIG-pattern, a very simple application was designed. This application involves the generation of random sequence of items, which are further sorted. A better understanding of the GIG applicability and power, however, can be seen in section 10.

The proposed application can be subdivided into the following sub-processes (algorithm components): generation of a random sequence of items; sort of these items; and display of the sorting items. The sort sub-process is implemented here using the Heapsort algorithm derived from [11]. Any one of the sub-processes can be modified afterwards to another one, generating a different solution algorithm.

The Heapsort algorithm written in natural algorithmic language is described in Figure 4. This algorithm is an example solution to a very well known problem, which has many solutions.

```
HeapSort (A)
Buil_Max_Heap (A)
for i ← length[A] down to 2 do
Exchange A[1] ←→ A[i]
heap-size[A] ← heap-size[A] –1
Max_Heapify

Build-Max-Heap(A)
Heap-size[A] ← length[A]
For I ← length[A]/2 downto 1 do
Max-Heapy(A,i)

Max-Heapify(A,i)
l ← LEFT(i)
r ← RIGHT(i)
if l <= heap-size[A] and A[l] > A[I]
   then largest ← l
   else largest ← i
if r <= heap-size[A] and A[r] > A[largest]
   then largest ← r
if largest != I
   then exchange A[I] ←→ A[largest]
        Max-Heapify(A,largest)
```

Figure 4. Heapsort Algorithm

The algorithms organization in the form of a direct acyclic graph can be seen in Figure 4.

```
Main Program

I. Generation of aleatory data
II. HeapSort
 II.I Build-Max-Heapify
 II.I.I Max-Heapify
III.Print
```

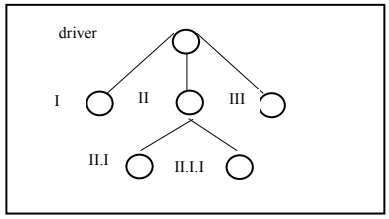


Figure 5. Main program and correspondent GIG direct acyclic graph

In this example the decomposition of the domain data, is very simple. It generates only the *HeapSortData* data type, which is used by all Heapsort subcomponents.

The created *AlgthNode* classes are derived from the process organization in Figure 5.

Each *AlgthmNode*, that is an algorithm component, places calls to its children nodes, which implement processes inside the whole process. The logic is defined inside each *AlgthmNode* subclass and it references the execution of a child algorithm, independently of the routine that is in that child.

Figure 6 shows the UML class diagram, which was created to implement the application classes in C++ [12], which applies the GIG-pattern. Some classes, described bellow, were created to implement the GIG pattern and solve the sorting example:

- The *Factory* class follows the GIG implementations suggestions, described in section 7. They define a common interface to materialise *AlgthmData* and *AlgthmNode* objects from a data source. The *FactoryHeapSort* class was created to materialise objects from the classes created to represent the Heapsort algorithm in GIG.
- The classes created to represent the *AlgthmNodes* are: *GenerateRandomAlgthmNode*, *HeapSortAlgthmNode*, *BuildMaxHeapAlgthmNode*, *MaxHeapifyAlgthmNode*, and *PrintAlgthmNode*, each one being related to a procedure described in the HeapSort algorithm, see Figures 5.
- The *HeapSortData* is an *AlgthmData* subclass created to store the sequence of items to be sorted and some control variables.
- The root (driver) of the whole process is here the *GenerateRandomData* .

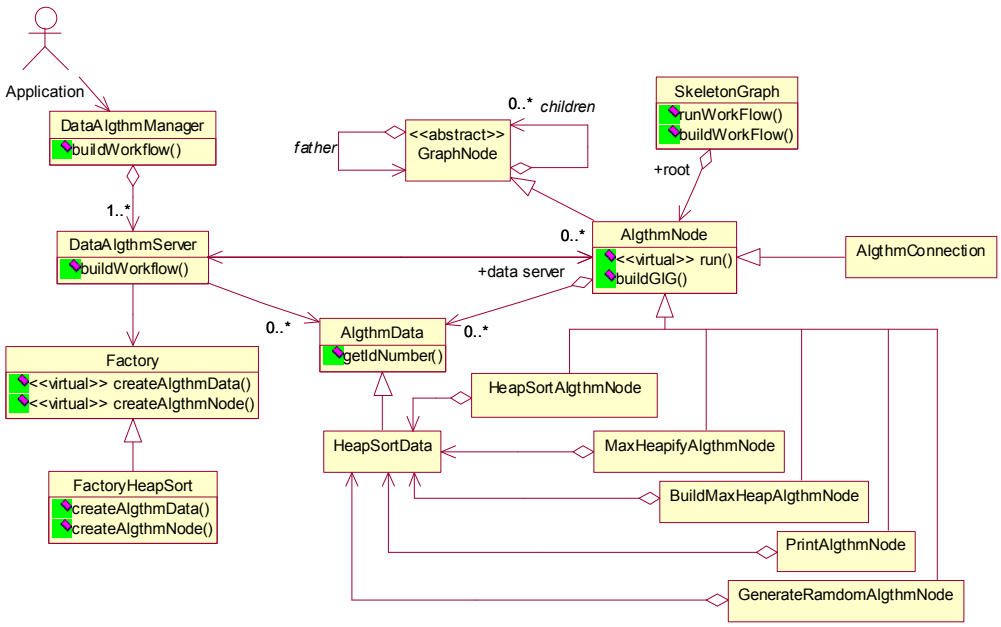


Figure 6. The Class diagram of the GIG implementation and example classes

The sample code presented in Figure 7 is an extract from the implementation of the class *HeapSortAlgthmNode*. With this example, we can understand how the implementation of the *run* method of an *AlgthmNode* class calls the children nodes in its code. In this example the *HeapSortAlgthmNode* class order its first child to run, before some other tasks are performed.

```
void HeapSortAlgthmNode::run()
{
    this->runChild(0); //run Build-Max-Heap
    for( int i = heap->size(); i >= 2; i--)
    {
        heap->swap(1,i);
        heap->decrementHeapSize();
        this->runChild(1);//run Max-Heapify
    }
}
```

Figure 7. Implementation of the run method for the class HeapSortAlgthmNode

10. Second Example

In [6], we present an application of GIG in FEM simulators. Usually, it is observed that an algorithm defined for the solution of a problem by the FEM has repeated (similar) hierarchical structures. Thus in the pursuing of a high degree of reusability, a framework considering hierarchical levels of processes were used, where each level may have several possibilities of algorithms, and can be easily described by a GIG graph. The whole hierarchy is represented making the connections between the different levels and generating a complete graph. Global Skeleton, the Block Skeletons, the Group Skeletons, and the Phenomena procedures define those levels [2]. This levels satisfy a number of requirements, such as: (i) to separate less reusable modules from reusable ones; (ii) to make it more comprehensible the decomposition of the simulation data among the several processes; (iii) to make it possible the dynamic re-configuration of the simulator through the replacement of reusable modules.

For instance, the global Skeleton articulates time loop (if present), adaptation iterations and defines processes involving the call of Block Skeletons. Block Skeletons may define different solution strategies for different Groups, thus, articulating Group processes. Group Skeletons articulate their phenomena procedures in very specific less reusable ways. It is in this level that solvers for algebraic systems are applied. Phenomena are the abstraction of the entities being simulated. All those skeletons can be implemented as objects from classes following the GIG pattern (see Figure 8). Therefore, the GIG would allow for the realization of the interoperability of the different levels of computation (by automatically plugging the lower level skeletons in the higher ones).

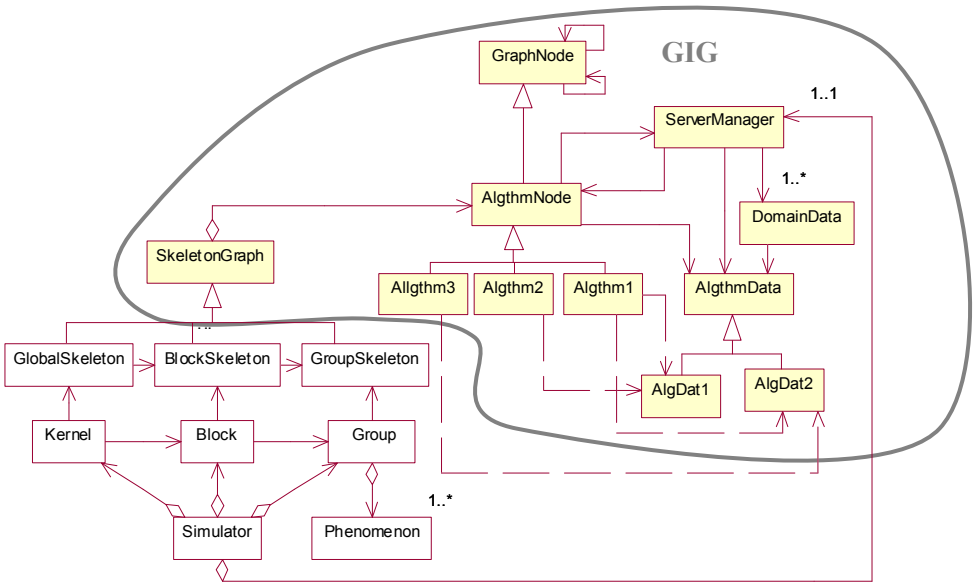


Figure 8. FEM Simulator and GIG classes

In the example described below, we consider a FEM simulator specification . This kind of simulator is capable of solving, for example, problems involving transient phenomena, where the phenomena context includes linear temperature-dependent elasticity, rigid body motion and linear heat transfer [2,6]. Only two blocks are needed in the present case. The number of Groups depends on the phenomena types present in a specific simulation. The number and type of phenomena depends as well on the simulation being carried out. In the ith-Block Skeleton Nig is its number of groups.

```
I.From Blocks i = 1 until 2
  I.0)Retrieve initial state for Block i
  I.I)Compute initial time step Δt_i for Block i
  I.II)Compute initial auxiliary data for Block i
II.Compute initial Δt = min_{1≤i≤2}{Δt_i},set time instant t_1=0
III.While t_1 ≤ T_max do:
  III.0)Set t_0 = t_1 and t_1 = t_0 + Δ t
  III.I)For Block i = 1 until 2
    III.I.0)Solve for Block i
    III.I.I)Compute next time Δt_i for Block i
  III.II)Compute next time step Δ t = min_{1≤i≤2} {Δ t_i }
  III.III)Continue with time iteration
IV.End of the simulation
```

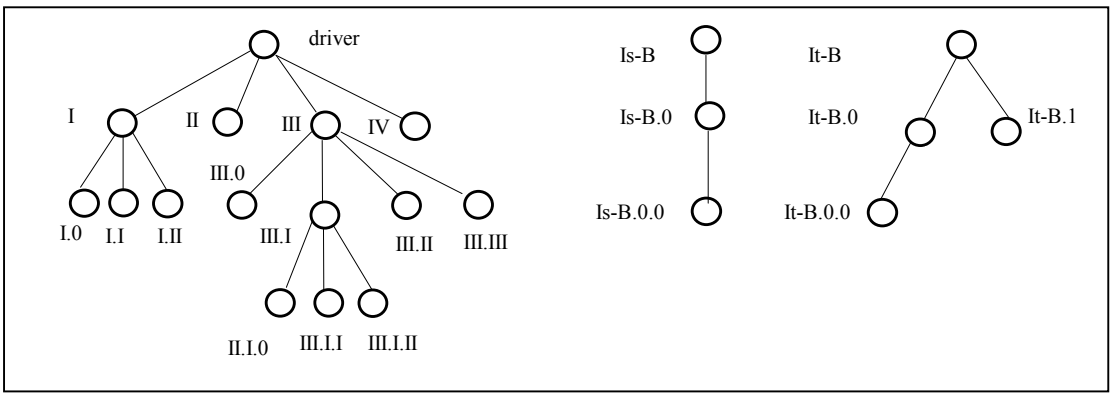
Figure 9. Global Algorim Skeleton

Figure 9 shows the Global Skeleton, while Figure 10 shows two Block Skeletons. Figure 11 and Figure 12 present the GIG direct acyclic graph to implement Global and Block Algorithm skeletons.

```
Is-B^i)Retrieve Initial State for Block i (see(I.0)):
      Is-B^i.0)For r = 1 until Nig
        Is-B^i.0.0)Group r, compute phenomena initial states
It-B^i)Compute initial time step for Block i (see(I.I)):
      It-B^i.0)For r = 1 until Nig
        It-B^i.0.0)Group r, compute Initial time step Δr
      It-B^i.I)Set Δt^i = min  1≤ r ≤ Nig  {Δ r }
```

Figure 10. Block Algorithm Skeletons

As it was already said, there should be *AlgthmData* objects, which will contain the needed problem and process data needed by each *AlgthmNode* object. A specialization of *AlgthmNode* is *AlgthmConnection*, which is defined whenever a lower level process is to be called up. Its *AlgthmData* object includes pieces of information needed in the identification of the lower level skeleton that will be plugged in the Algorithm Skeleton Graph. This identification concerns a driver *AlgthmNode* object (from another graph, integrating in this way the graphs presented in Figure 11 and Figure 12), which will substitute the related *AlgthmConnection* object.



Figurel 1. Global Alg.Skeleton graph

Figurel 2 Block Alg.Skeletons graphs

11. Consequences

In what follows we make some considerations about the forces treated by the proposed pattern.

We can observe **positive forces** for the use of the GIG-pattern:

- Easiness of translating from algorithmic language into computer processes and simplicity in the process definition. It supports an organisation in a graph level, providing the distribution of code in a very flexible way, not compelling a rigid division of code. To improve simplicity in process definition we try to: avoide unnecessary levels of details and maintaining similarity to the predefined algorithmic structure.
- Different users have evaluated this pattern with success, in applications with different levels of complexity. A simple example can be seen in section 9, and a more complex one in [6].
- Support for different levels of granularity of the defined processes. It allows a flexible representation for a mixture of scales, since it does not restrict the levels of programming into which the code is defined. Differently, in [1] the workflow must be defined in terms of a set of node types that are already been coded in the programming language level.

- It can be applied to any domain solution, through the definition of specific domain data classes and algorithms, as it can be seen from the pattern participants, in section 6.1,
- It allows the test of individual parts of the process independently, reducing the error occurrences in the coupling of processes.
- It allows the reuse of entire solutions, making changes in specific points. In GIG, it is easy to change parts of the graph, maintaining the other ones intact.
- It allows the graph change (that is, the process change) at run-time. This is achieved through the GIG intrinsic dynamic structure, as was shown in section 6.2. Data and process can be defined at run-time, depending on GIG implementation, once the pattern can be easily extended to incorporate design patterns like [9], as presented in section 8.

Some **negative forces**, or restrictions, can also be identified:

- The pattern makes severe restrictions on the graph structure, requiring it to be an acyclic graph. The designer is not allowed to define neither recursive iterations nor loops out of the node code.
- GIG-pattern makes no explicit reference or imposition for the use of a specific set of process types, differently from [1]. We can consider that this may cause a loose of workflow-refined control. It is the programmer responsibility to define and manage this organization, if required by the application.
- Flow control is inside each node code. This can bring difficulties to some part of the process adaptation and control.
- Synchronization is not GIG-pattern responsibility. GIG does not define a specific structure to deal with process parallelism and processes synchronization. To allow the definition of processes parallelism, the programmer has to deal with extra complexity. GIG-pattern requires unnecessary levels of repetition, that is the replication of whole process graph branches arising an excessive use of memory.

We may summarize saying that this pattern it is **not so appropriate** for applications that are more simple and do not require exchangeable components, modularity or articulation of components. Also it is **inappropriate** for applications where there is a need of a high level of refinement in the programs code, or if they need to process synchronization and parallelism; in these cases, an alternative is the use of the Micro-workflow proposal, described in [1]. However, through the use of the Micro-workflow alternative one of the worth thing you loose is simplicity and the level of granularity; the translation from algorithmic language is not a so direct mapping losing in this way some levels of abstraction. The application of the GIG pattern to simple application can be more expensive them a simple solution, on the other hand it provides extra facilities like reuse, flexibility for new solutions, domain independence, etc.

12. Related patterns

The following patterns, can be used in the GIG-pattern:

- *Factory Method* [10], which can be used to materialize objects for workflow management;
- *Template Method* [10], used to define skeletons of algorithms in *DataAlgthmServer* class;
- *Composite* [10], used to implement the *AlgthmNode* class functionality in the framework.
- *Proxy* [10], used t in AlgthmConnection class;
- Adaptive object-model patterns, such as *TypeObject* [9], shown in variants section.
- *FEM-SimulatorSkeleton* [2]achieves great benefit from the GIG approach.

13. Known uses

Many numerical algorithms show the very same organizing structure, which was abstracted by the GIG-pattern. Some of these numerical algorithms are: mesh generation procedures, geometric reconstruction from planar slices and integration of geometric reconstruction procedures, and so on.

Despite of being a generic solution that can be applied elsewhere, the users of this pattern have been scientists and engineers. The GIG-pattern has been applied with success in the development of different FEM simulator applications, and in a variety of other numerical methods in computational Mechanics. Other known user, which applies GIG pattern, is a specific environment called Plexus, whose objective is the construction of FEM simulators for treating problems involving coupled multiphysic phenomena [2,6]). This environment applies GIG as general solution for the numerical methods and articulation strategies for solving groups of phenomena [15]. Section 10 has given some details. Other less complex processes were also implemented following the GIG pattern like mesh generation; these processes have requirements related to modularity and exchange of components, since they have specific parts that have several kinds of implementations, which can be exchangeable. The mesh generation is described with a little more detail in what follows.

Mesh Generation Case

The mesh generation case can be shortly described as: a mesh is a partition of a geometric domain into simple geometric entities (triangles, tetrahedra, hexahedra, etc) called geometric finite elements (or simply elements). Below we present the algorithm for a particular mesh generation, which, given a plane straight-line graph (PSLG), generates a mesh of triangles. Those triangles should not violate the lines in the graph and their vertices should be the points used to describe the graph. The method used is based on the constrained Delaunay method.

```
I.  Data input (PSLG)
II. Generate the bounding box for the PSLG
III.Build the initial mesh of the bounding box
IV. For each point in the PSLG do
    IV.I.  Insert point
       IV.I.I.  Find elements affected by the new point
       IV.I.II. Eliminate those elements obtaining the affected region (AF)
       IV.I.III Build new elements from the new point and boundary of AF
V.  Find a line of the PSLG such that it is not an edge of any triangle
   (negative line)
XIV.   While there still is a negative line do
       VI.I Compute the middle point of the line
       VI.II insert middle point (see IV.I)
VII. Eliminate those triangles, which have any point of the bounding box as
     one of their vertices.
VIII.Data output
```

Figure 13. Block Algorithm Skeletons

Observe that there are fifteen processes, including the driver (which executes the procedures I- VIII). Each one of those processes may be encapsulated in an object of a class derived from *AlgthmNode*. The Data Domain of this problem can be decomposed in such a way that all *AlgthmNode* objects will have access only to the data it needs. For instance, the process *III.Build an initial mesh for the bounding box* will need the bounding box and will build the initial mesh, which will be stored in a place in order to be accessed by other nodes. That decomposition will give rise to the classes derived from AlgthmData. The whole set of data pieces depend on the geometric data structure used by the developer. For instance, it can be seen that some structures have to be present: (a) PSLG (accessed by

I, II, IV and V); (b) bounding box (accessed by II, III and VII), (c) mesh (accessed by III, IV.I.I, IV.I.II, IV.I.III, V, VII and VIII), (d) auxiliary data (many, it depends on the designer). All those pieces of data will be encapsulated in objects of classes derived from *AlgthmData*.

Observe that there are many different ways of performing each one of the tasks described in the above algorithm. For instance, *IV.I.I find elements affected by the new point* concerns a search method in a geometric database of triangles, looking for a triangle whose circumscribed circle contains a given point. There are a lot of search methods available in the specialized literature, each one with its advantages, drawbacks and dependence on special data structures. Replacing the current method by a new one will not affect any other place in the graph and can be done dynamically, that is, at run time.

Entire branches can also be changed as well. For instance, the process *IV.I. insert point*, can be changed by plugging another method to perform that task. That means that all the subsequent processes (children nodes) will be also changed. Besides the severity of the change in the methods needed by the algorithm, all the substitution work is automatically performed.

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