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DYNAMIC ACCELERATOR MODELING

HIROSHI NISHIMURA

ACCELERATOR and FUSION RESEARCH DIVISION
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

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H. Nishimura
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

Abstract

Object-Oriented Programming has been used extensively to model the LBL Advanced Light Source 1.5 GeV electron storage ring. This paper is on the present status of the class library construction with emphasis on a dynamic modeling.

I. INTRODUCTION

The Advanced Light Source (**ALS**) at Lawrence Berkeley Laboratory represents one of the new generation of electron storage rings being developed for high brightness synchrotron radiation experimentation [1]. These low emittance storage rings require high accuracy, multi-parameter accelerator models for trajectory calculations and model-based control systems. During the lattice design phase, computer-intensive off-line modeling and simulation programs were developed to study magnet structures and tolerances [2]. The models were later made more flexible and interactive by taking advantage of Object-Oriented Programming(**OOP**) languages and techniques [3]. This paper describes the next logical step to integrate the modeling software with the accelerator control system in order to provide model-based control and automated analysis of the accelerator.

II. DYNAMIC MODELING AND OOP

A. Dynamic Modeling

Traditionally, a tracking or modeling code supports only one accelerator configuration and it is tightly coupled to a particular approximated Hamiltonian and its integrator. **Dynamic Modeling** [4] is a new modeling technique that supports multiple accelerator configurations at run time. It also isolates the simulation code framework from the detail of its numerical integrator. These tasks can be supported quite naturally using an **OOP** concept. The general software requirements that include correctness, robustness, extendibility, reusability and compatibility [3] are all supported by **OOP**. Additional specific requirements for the accelerator control system described in the reference [5] also requires **OOP**.

Dynamic Modeling is just one of the merits we can get from **OOP**. Instead of creating a virtual accelerator using all the lines of a code, we can construct a class of accelerators and create, manipulate and annihilate multiple virtual accelerators at run time. It makes the calibration of the model efficient because virtual machines behave like *dynamic* variables. It also makes the modeling of operations with undulators easier by keeping many configurations with different undulator settings.

B. Class Libraries

Our effort has been focused on the development of class libraries which serve as building blocks of various kinds of applications. There are three kinds of class libraries: modeling, hardware access and applications. A class for modeling and simulation is called **Goemon** [6] and supports **Dynamic Modeling**.

C. Modeling on the ALS Control System

The programs we used in the lattice design phase [2] were developed on VAX/VMS and written in VMS Pascal. The first step to create **Goemon** was to extract a linear modeling engine from them. Then it was rewritten in ANSI C for the use on Unix workstations and IBM PC clones that have on-line access to the hardware of the accelerator [7]. We used **Eiffel** (v2.3) [8] on Unix to construct a class library at a very high level, keeping the numerical engine in C [4]. Now it has been completely rewritten in C++ on PC clones running Microsoft Windows 3.1 or NT and is being ported to Unix. This version covers the range from the lower level numerical engine to the higher level optics calculations and fittings.

D. Design and Analysis

The Object-Oriented Approach was applied not only for programming but also for design and analysis. We used the

Object Modeling Technique [9] with ***OMTool*** [10] for object design and analysis. In this notation, a class is represented as shown. (We may omit names of attribute and operation in this paper.)

The physics part (**Goemon**) was designed to have:

1. Simplicity
2. Distinction between Component and Machine.
3. Separation from Hardware Layer
4. Separation from Graphics
5. Separation from Machine Operation

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Simplicity is important in the class library construction. The choice of inheritance or aggregation was the main issue for us. Component and Machine corresponds to magnets in a warehouse and an accelerator assembled from them. But the term *Machine* is usually used for the hardware, therefore we will call it *Accelerator*. Separation is to keep the model portable. Since the low level machine access can be performed without modeling, a model layer should be independent from it. Graphics heavily depend on the development environment, therefore the model should be separated from them. Machine operation means various kind of parameter fitting and machine study. Since it accesses the hardware and requires graphics, it must not be a part of the model. These requirements on separation can be well described as follows: Model, hardware access and graphics should be supported independently by their own class libraries and serve as suppliers to the client classes that include machine operations and studies. This is again the matter of *has-a* and *is-a* relationship.

III. CLASS LIBRARIES

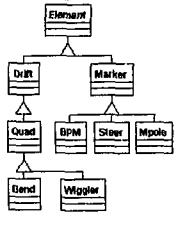
Currently, we classify as follows:

Physics (Goemon)
Component Class
Accelerator Class
Hardware
Device Class
Client
Graphics Class
Operation Class

We describe the structure of 5 classes mentioned above.

A. Component Class

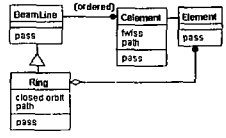
A beam line is a series of elements like drift spaces, magnets and monitors. The class **Element** serves as a base class for these elements. **Drift** is a class for drift spaces and a base for thick linear elements like quadrupole and bending magnets. **Marker** is a base class for markers and thin elements that cover multipole magnets. **Wiggler** is treated as a special quadrupole which will be enough for elementary linear optics calculation. When a better model for a wiggler/undulator is required, it will be a derived class of it.



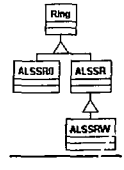
The most important method of **Element** is *pass* that transfers a particle $v=(x,p_x,y,p_y,\delta p/P_0)$ through it. Here (x,y) is a transverse coordinate, (p_x,p_y) is the canonical momentum, δp=momentum deviation, P_0=nominal momentum. The standard 4x5 matrix formalism is used as the integrator but it can be easily replaced with another formula making use of the inheritance mechanism without influencing other parts.

B. Accelerator Class

This is a class for virtual machines. **BeamLine** represents a beam transfer line that is a list of **Component Class** objects. It has an array of **Celement**. **Celement** class has an **Element**, path and Twiss functions at each position. **Ring** is a circular **BeamLine**. It has a collection of **Element** objects to assemble a beam line. **Ring** is the class that directly supports dynamic modeling. An instance of **Ring** is a virtual accelerator. The figure (right) shows the relationship between Component and Accelerator classes.



The **ALS** storage ring classes are derived from **Ring**. **ALSSR0** is the ideal ring with full symmetry, **ALSSR** for full lattice and **ALSSRW** with wigglers/undulators. **ALSSR** has knobs to manipulate any magnets around the ring freely. Then it calculates all the linear optics, synchrotron integrals and related parameters.



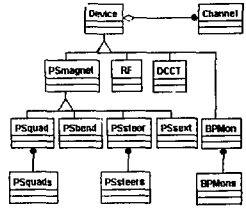
C. Graphics Class

A graphical user interface library should support both windows environment on Unix workstations and PC running MS Windows. We use **zApp** [11] on PC to cover Windows 3.1 and NT. We will be using **zApp** when OSF/Motif version is released. A customized graphics class for **ALS** is being developed using **zApp**.

D. Device Class

Layered on top of the **ALS** control system, **Device** provides virtual devices. **Channel** corresponds to each hardware access channel (**DMM** database entry [7]). The figure shows that **Device** has one or more channels.

PSMagnet is a base class for magnet power supplies. Since there are many quadrupoles, steering magnets and BPMs and are frequently used by application classes, dedicated access is provided.



Previously, **Device** was a descendent of **Channel** and served in the commissioning phase for process

controls. But this design turned out to be inadequate to handle devices that have many channels and is being rewritten as described above. This is also a matter of *is-a* and *has-a* relationship.

PSmagnet is for the magnet power supplies and contains subtasks to perform slow settings of currents. **PSquads** and **PSsteer** are for ganged operation that synchronizes subtask objects. **DCCT** is a class for a beam current monitor that keeps track of beam current intensity. **BPMons** handles 96 beam position monitors and have been used intensively during the commissioning period.

E. Operation Class

This supports various kinds of parameter fitting operations on the **Accelerator** object which covers tune fitting, orbit correction and undulator compensation. This class is a client of all other classes mentioned above and is specific to the **ALS**. The construction of this class has just started. Currently we have **Smatrix** and **Bump**.

Smatrix is for the sensitivity matrix manipulation including file access. An on-line data taking application and **Goemon** both use this class to have a common data format.

Bump is for local orbit bumps with 3 steering magnets. It can be associated with **ALSSR** or **Smatrix**, which makes both model-based and model-free local orbit corrections possible. As **Bump** is not a part of the model, it is possible to pass its objects to the real-time control layer for fast orbit corrections.

IV. FUTURE PLAN

The following items are on the list.

A. Persistency

As **OOP** itself does not support persistency, device objects must read and write the values of their internal parameters including the nominal current settings from/to files. There is a need for a database management system to administer these values with access to the objects. We are evaluating the Object-Oriented Database Class Library **Raima Object Manager** [12] for this purpose. It gives persistency to objects by using multiple inheritance.

B. Model-based Control

The effort to implement a model-based control layer on top of the existing control system has just been started for the operation with undulators. The migration of **Goemon** to the control system will be done by providing the server-client mechanism over the network. **OOP** in this area has not yet been well investigated.

C. Data Analysis

The **ALS** storage ring was operated for 6 weeks with RF. During that period, most of the machine studies were to measure fundamental parameters (closed orbit, tunes, chromaticities and sensitivity matrices) and they have not yet been fully analyzed. Several application programs based on the class libraries are being used, but there should be an effort to construct a class for data analysis.

V. ACKNOWLEDGMENTS

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