Computer Science Seminar Series

April 18, 2003

Integrating Object-Oriented Design and High-Level Petri Nets in Development of Concurrent Software Systems

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Motivation

- **Imperative from Mellor and Shlaer (1994):**

  "The ability to execute the application analysis model is a sine qua non for any industrial-strength method because analysts need ***to verify the behavior of the model*** *with both clients and domain experts"*

- **Software development:**

  \- **orthogonality between pragmatics and theory** - pragmatics attributes and theory attributes are/should be mutually independent; i.e. it is possible to develop software systems with/without theory

  \- **pragmatics attributes:** modularity, readability, reusability

  \- **theory attributes:** formal analysis of software properties, model's executability

Introduction

- **Object-Oriented Design:**
  - well established design techniques with classes, responsibilities, and collaboration graphs being result of some OOD method
  - lacks analysis, verification and validation (V/V) methods of the designed system
  - lacks formal specification of concurrency and partial ordering of events
  - support for inheritance, polymorphism, and dynamic binding
  - UML modeling provides Message Sequence Chart (MSC) for interactions and ordering of objects; some actions may constitute co-regions, i.e. they remain unordered

Introduction, ctnd.

- **Petri Nets:**
  - well-defined formalism of parallel/distributed system modeling with graphical and algebraic representation
  - **conflict** representation and resolution (as a mechanism of choice)
  - **confusion** representation and its algorithmic detection (as co-existence of concurrency and conflict)
  - **time** representation (delay and duration) and time annotations as part of arc/transition inscriptions
  - **resource allocation** explicit representation
  - support for **abstraction and refinement** using **vicinity preserving and general Petri net morphisms** - elements of hierarchical structuring
  - weak support for composition of Petri net-based models
  - lacks clear and effective specification of system design techniques
  - strong analysis, verification and validation techniques and broadly available CASE tools

Integration of Object-Orientedness and Petri Nets

- **Three approaches of integration of Petri nets with object-oriented concepts:**

  - giving a formal basis to an object-oriented language or methodology

  - extending Petri nets by the use of complex data types for tokens

  - using object-oriented concepts directly in the Petri net formalism

- **Integration of objects with Petri nets is difficult because modeling and structuring power of objects is often in conflict with the proving facilities of Petri nets (**examples: using of complex data types for tokens, support for inheritance and polymorphism)

- **rapid prototyping of PDSS -** modeling, analysis, V/V, and performance evaluation of the designed system

Integration of Object-Orientedness and Petri Nets

- **OO and Petri nets are complementary methodologies**
- **Goal:**
  - use Object-Oriented methodology/technology on the design stage
  - use Petri Nets on the analysis and Verification/Validation stage
- **Approach #1: "Objects inside Petri Nets"**
  - increases token's intelligence
  - represents a designed system as a single, large Petri Net
  - does not contribute to abstraction of Petri Nets
- **Approach #2: "Petri Nets inside Objects"**
  - to model the inner behavior of objects (as sequential or concurrent)
  - very valuable starting point for the abstraction of Petri Nets
  - usually Object-Based rather than Object-Oriented

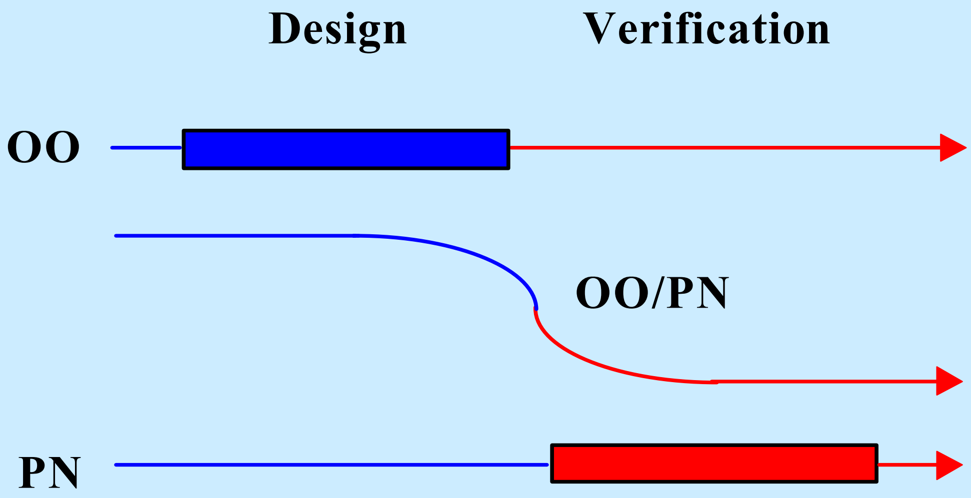
Integration of Object-Orientedness and Petri Nets

- **Petri Nets First - Top-down Approach:**
  - start with a Petri Net and represent a system by means of PN
  - objects are tokens or sub-nets
  - beneficial for verification (PNs support V/V)
  - abstraction is used to relate objects to tokens and sub-nets
- **Object Orientedness First - Bottom-up Approach:**
  - start with a result of some kind of OOD
  - Petri Nets represent classes and object interactions
  - beneficial for design (full power of design method can be utilized)
  - single, large Petri Net; no abstraction
  - **object** = (data structures, operations, object's behavior)

Integration of Object-Orientedness and Petri Nets, ctnd.

- **Sibertin-Blanc & Bastide -** Petri Nets with Objects (PNO) - tokens contain references to OO data structures and **Cooperative Objects (COO)** - objects with Object Control Structure (OBCS) - **CASE tool SYROCO**
- **Lakos -** Object Petri Nets (OPN) developed from Colored Petri nets through a serious of formal transformations that make **Object Petri Nets** behaviorally equivalent to Colored PNs - **CASE tool LOOPN**
- **Buchs & Guelfi -** Concurrent Object-Oriented Petri Nets; an object has an internal behavior defined by an algebraic net - **CASE tool CO-OPN/2**
- **Valk -** *Relating Different Semantics of Object Petri Nets*, Report, 2000, Petri Nets as Dynamic Objects; **Communicating OPNs**
- **Moldt - Object CPN** - an extension of CPNs

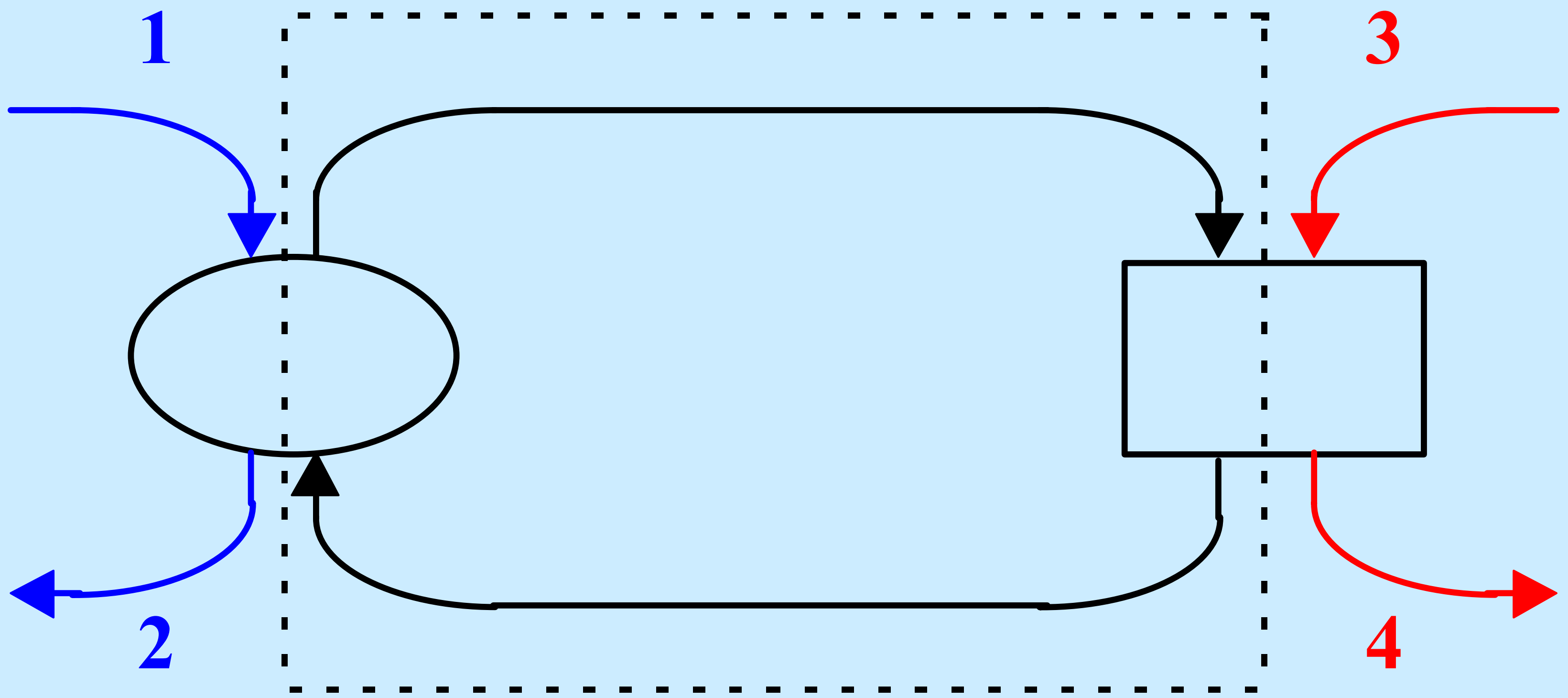
Integration of Object-Orientedness and Petri Nets - the hybrid approach



Abstract Node

- **Symmetry and Abstraction Constructs:**
  - asymmetry of existing abstraction constructs (Lakos, Petri)
  - non-unified constructs (abstract places/abstract transitions; do not emphasize the duality of places and transitions)
  - unified abstraction construct **- Abstract Node (AN)**
- **Abstract Node:**
  - AN as an abstract place and AN as an abstract transition
  - constructed by connecting a place (AN-place) and a transition (AN-transition) by two arcs with parametrizing inscriptions in a loop
  - duality between sets {1,2} and {3,4} of arcs as duality between abstract places and abstract transitions
  - if arcs {1,2} are used for embedding an abstract node into the net then it behaves like abstract place; if arcs {3,4} are used then it behaves as an abstract transition

Abstract Node



Abstract Node versus Abstract Places and Abstract Transitions

- **Natural Extension of Places and Transitions to Abstract Places and Abstract Transitions:**
  - **abstract places** may store but not modify tokens
  - **abstract transitions** may modify but not store tokens
- **Desired Solution:**
  - **abstract places** need to modify tokens (with token conservation)
  - **abstract transitions** may store tokens with some restrictions applied (atomicity of internal actions)
  - AN-place can store tokens and AN-transition can modify them
  - the modification of tokens by AN (that acts as abstract place) is done by firing AN-transition, which results in a change of color of the token of the AN-place

Abstract Node versus Abstract Places and Abstract Transitions, ctnd.

- **the internal state of AN** (that acts as abstract transition) is stored in the AN-place; AN-transition can modify an internal state and synchronizes the actions associated with its external incident arcs (arcs 3 and 4)
- **AN can be constructed using regular CPNs** without any modifications or additions; the level of abstraction can be varied by changing inscriptions of abstract node's arcs (AN-arcs) and a color set of AN-place
- **AN is the highest level of object abstraction** which is refined to interfaces and implementations

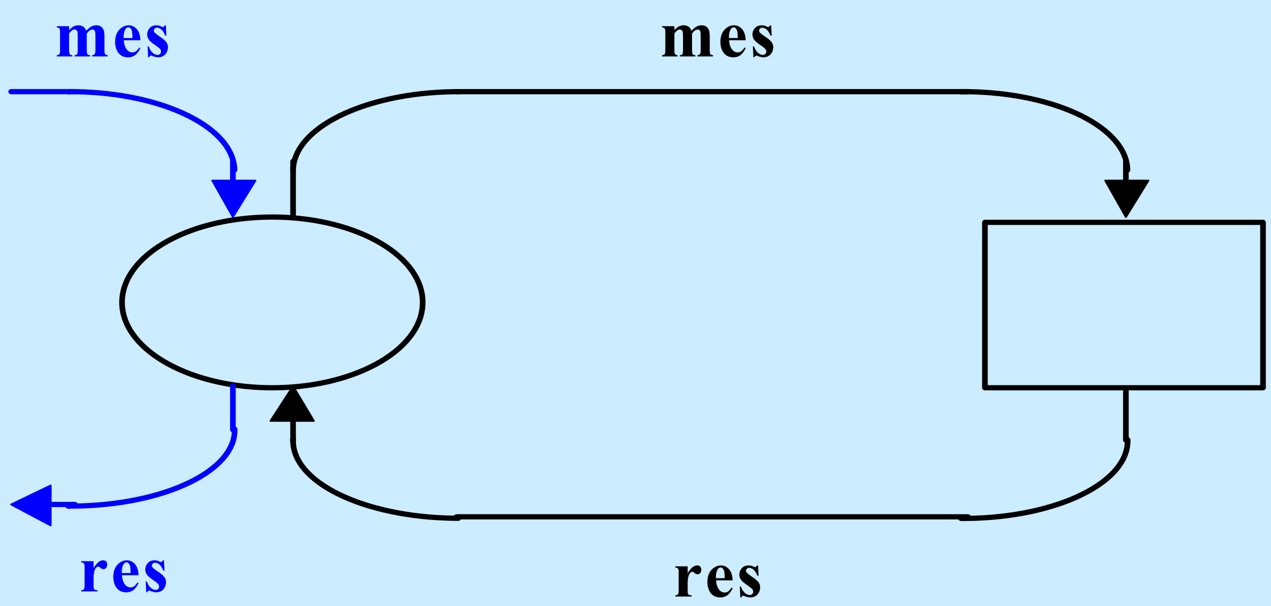
Abstract Node and Objects

- **Abstract Node as an Object:**
  - AN encapsulates both data and actions (tasks)
  - AN is the highest level abstraction of an object
  - single object level is not the highest possible level of abstraction for a system
- **Object Composition:**
  - objects can be combined to form **aggregates**
  - aggregate is an object, thus can be represented by a single AN
  - **aggregation is application specific** but it is supported by AN formalism
  - **semantics of aggregation** is supported by AN syntax

Abstract Node and Objects

- **AN are used to represent objects**
- **AN-place:**
  - serves as a message depository (incoming arcs)
  - serves as a place for retrieving results (outgoing arcs)
- **Distinguishing Between Message Tokens (Requests) and Result Tokens (Results):**
  - **message color set:** (object ID, message type, arguments)
  - **result color set:** (object ID, message type, result)
- **Object ID:**
  - unique object ID for all instances (objects) in the system
  - inter-object concurrency (instances can execute concurrently among themselves)
- **Message type used to:**
  - distinguish between those actions within a particular object
  - intra-object concurrency (concurrency between messages)

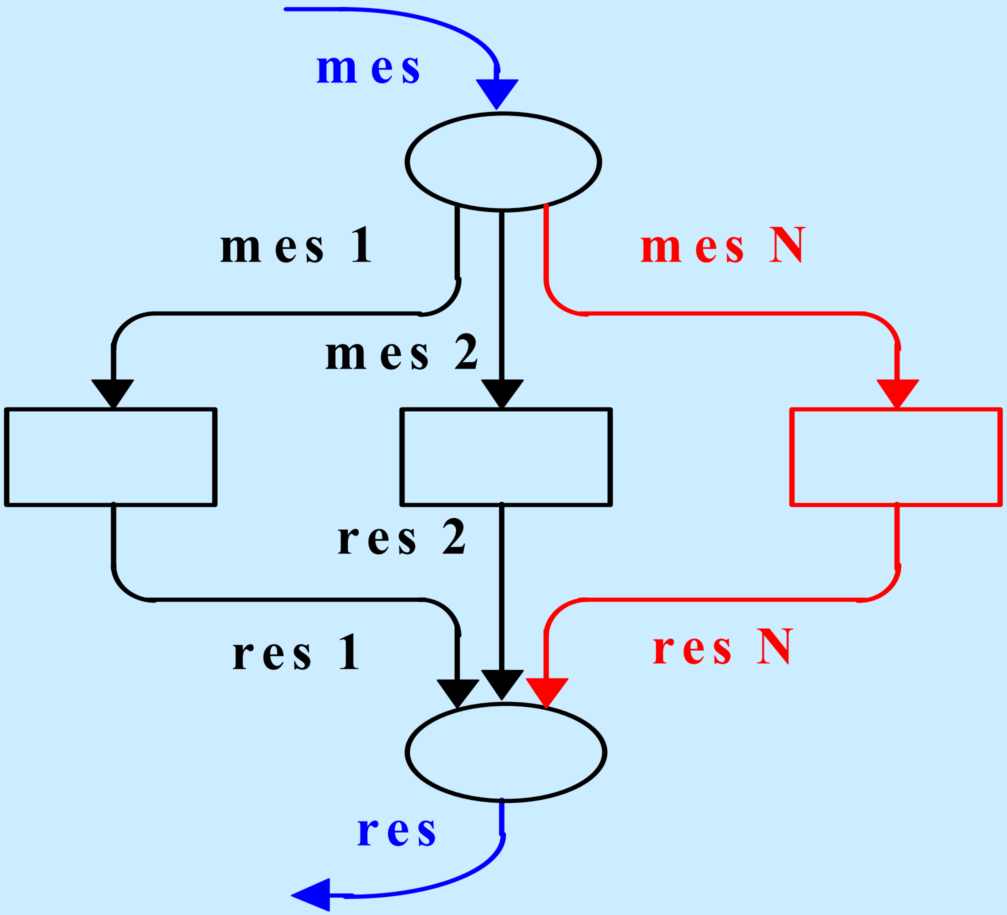
Abstract Node and Objects



Interface - First Level Refinement

- **One Object as an AN is Too Abstract**
- **Interface Refines AN in Two Ways:**
  - **it splits AN-place into two places**: the message depository place and the place for retrieving results
  - **it splits AN-transition** to as many transitions as the number of messages the object accepts
- **Each Transition (I-transition) Represents One Action of an Object**
- **Further Refinement of each I-transition is called an Implementation**

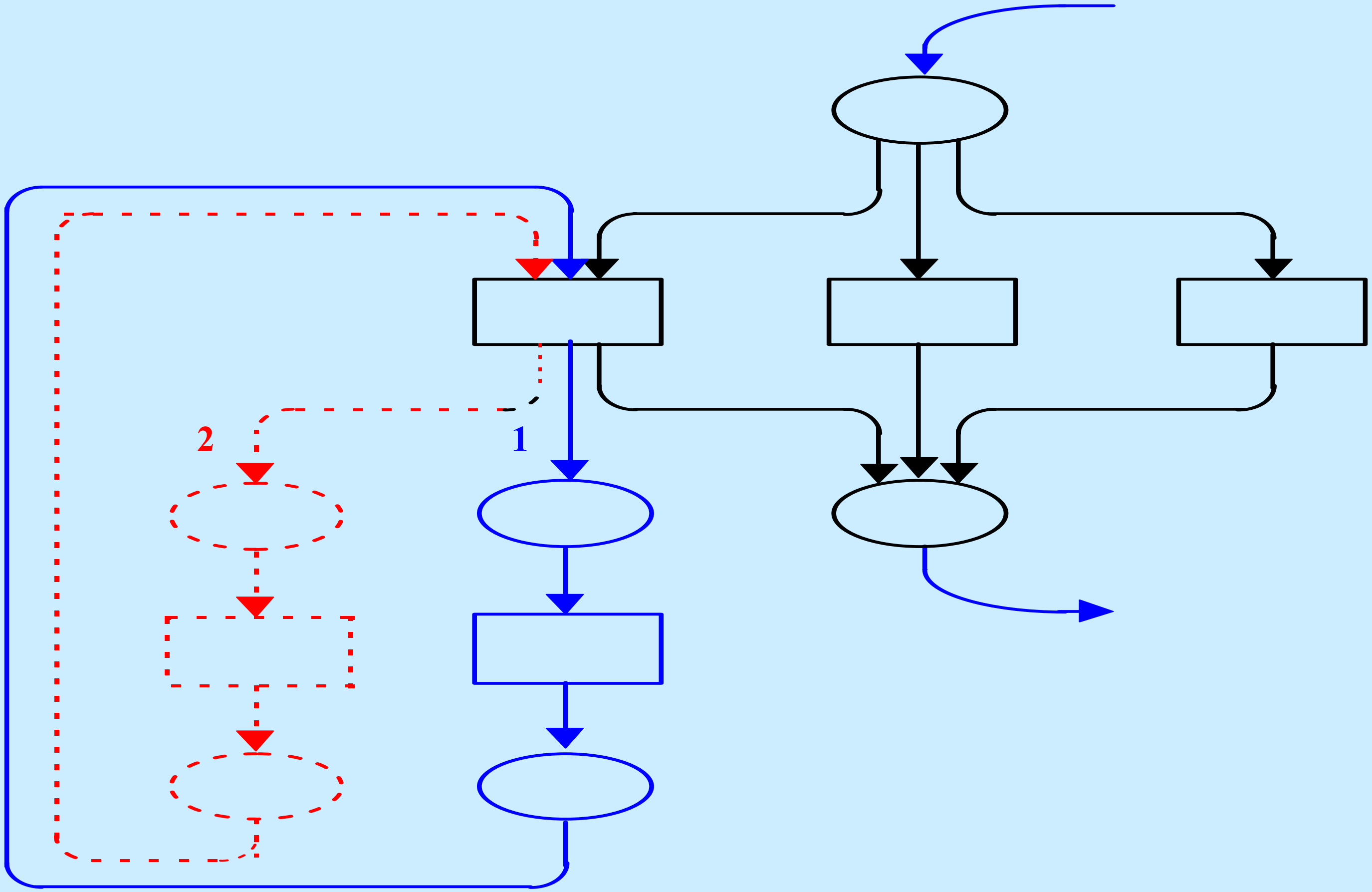
Interface - First Level Refinement



Method Implementations - Second Level Refinement

- **Implementations Provide the Most Detailed Representation of an Object**
- **Each Implementation Refines One Message Response:**
  - as sequential
  - as parallel; intra-object concurrency
  - as problem specific
- **Multiple Implementations:**
  - first implementation **solid blue**
  - second implementation **dotted red**
- **Binding and Arc Inscriptions:**
  - **by arc inscriptions:** arc 1 and arc 2 - can be static or dynamic (polymorphism and dynamic behavior of objects)

Method Implementations - Second Level Refinement



Inheritance versus Delegation

- **Inheritance. Effects on the Methods at a Class Level:**
  - **include the method** of a parent class without changes into a subclass
  - **do not include the method** of a parent class into a subclass
  - **modify the method** of a parent class in the subclass
  - **add a new method** to a subclass
- **Delegation. Object Level - Instances of Classes:**
  - **messages that are processed** without changes in a subclass are delegated to a parent class (the message is passed to a parent class)
  - **messages that are not processed in a subclass** do not have implementation
  - **modified methods** have new implementation and if needed can call a parent class
  - **new methods** have a new entry for both interface and implementation
  - **both single and multiple inheritance** can be implemented in this manner

Inheritance Anomaly

- **Single and multiple inheritance** require careful attention to avoid incorrect behavior of inherited class instances being a result of class interference on dynamics (behavior) of new inherited classes
- **three types of corrective actions to avoid inheritance anomaly:**
  - **state partitioning**
  - **state modification**
  - **history sensitiveness**
- all three types of inheritance anomaly can be cured with **modified pre-conditions and post-actions of methods** and with proper changes in dynamic behavior of objects (modified state diagrams or modified OBCS)
- **inheritance anomaly** can be assimilated into the method of OOD and PN integration by a modified implementation of methods with modified guards and modified effects of methods

Polymorphism and Dynamic Behavior of Objects

- **Objects have an interface and one or more implementations of each method**
- **Interfaces, Java Interfaces, Abstract Classes:**
  - multiple implementations of methods are viewed as multiple implementations of an interface (or abstract class)
- **Polymorphism:**
  - by doing the binding by the object ID we enrich the method with polymorphism of methods where object ID is unique number
  - **Object ID** has two fields: (unique class number, unique for each class instance number)
  - **polymorphism** is a binding by class number
- **Dynamic behavior:**
  - binding based on some variable in the arc inscription that is changed during the execution of an object

Conclusions

- **OO an PN are used without major modifications:**
  - method is just a set of rules and modeling with Petri nets
  - rules are expressed by means of Colored Petri Nets
  - rules can be expressed as a set of templates (being part of CASE tool)
  - library of commonly used objects can be another objective
  - SYROCO and LOOPN CASE tools were used to test this approach
- **Objects can be Created and Verified Separately:**
  - design/verification of single object level
  - design/verification of object interaction level

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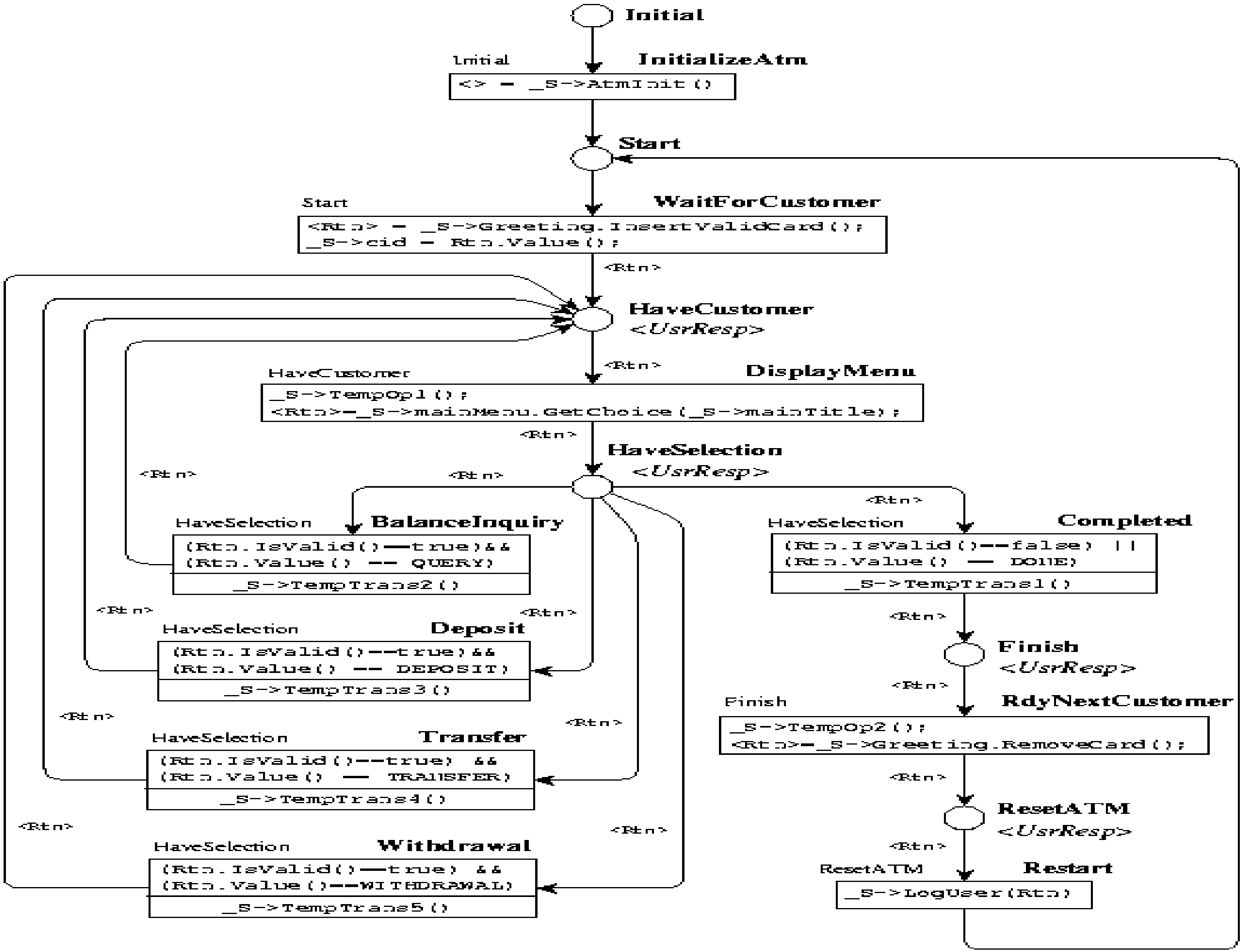
Future Work

- **testing the method** using average size example such as ATM System from Wirfs-Brock, Wilkerson, Wiener, *Designing Object-Oriented Software*, 1990
- using Petri net **vicinity preserving or general morphisms** that preserve certain structural and behavioral properties to provide abstraction and refinement building mechanisms during system specification by PNs (as a set of template transformations)

The ATM Machine

- The **ATM Class** OBCS Diagrams:
- - The **Root ATM** OBCS
- - The **ATMInit** Service OBCS
- The **BankCardReader** Class OBCS Diagrams:
- - The **Input()** Service
- - The **Eject()** Service
- The **Form** Class OBCS Diagram
- The **Menu** Class OBCS
- The **User Message** Class OBCS:
- - The **InsertValidCard** Service
- - The **RemoveCard** Service



Initial
Initial
InitializeAtm
<> = _S->AtmInit()
Start
Start
WaitForCustomer
<Rtn> = _S->Greeting.InsertValidCard();
_S->cid = Rtn.Value();
<Rtn>
HaveCustomer
<UsrResp>
<Rtn>
HaveCustomer
DisplayMenu
_S->TempOp1();
<Rtn>=_S->mainMenu.GetChoice(_S->mainTitle);
<Rtn>
HaveSelection
<UsrResp>
<Rtn>
<Rtn>
<Rtn>
HaveSelection
BalanceInquiry
(Rtn.IsValid()==true)&&
(Rtn.Value() == QUERY)
_S->TempTrans2()
HaveSelection
Completed
(Rtn.IsValid()==false) ||
(Rtn.Value() == DONE)
_S->TempTrans1()
<Rtn>
<Rtn>
HaveSelection
Deposit
(Rtn.IsValid()==true)&&
(Rtn.Value() == DEPOSIT)
_S->TempTrans3()
<Rtn>
Finish
<UsrResp>
<Rtn>
Finish
RdyNextCustomer
_S->TempOp2();
<Rtn>=_S->Greeting.RemoveCard();
<Rtn>
<Rtn>
HaveSelection
Transfer
(Rtn.IsValid()==true) &&
(Rtn.Value() == TRANSFER)
_S->TempTrans4()
<Rtn>
ResetATM
<UsrResp>
<Rtn>
<Rtn>
<Rtn>
HaveSelection
Withdrawal
(Rtn.IsValid()==true) &&
(Rtn.Value()==WITHDRAWAL)
_S->TempTrans5()
ResetATM
Restart
_S->LogUser(Rtn)