Правительство Российской Федерации

Федеральное государственное автономное образовательное учреждение высшего профессионального образования "Национальный исследовательский университет "Высшая школа экономики"

Факультет Бизнес-информатика
Отделение Программная инженерия

Программа дисциплины «Системы управления бизнес-процессами»

(на английском языке)

для направления 231000.68 – Программная инженерия
подготовки магистра

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Рекомендована секцией УМС по Бизнес-информатике
Председатель
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Утверждена Ученым Советом
факультета Бизнес-информатики
Ученый секретарь
_____ В.А. Фомичев
"____" _____ 2011 г.

Москва

I. Introductory Note

Program Author:

Professor, Dr. Irina A. Lomazova, Dr. Sci. (Comp.Sci.)

General Description of the Curriculum:

The course is delivered to master students of software engineering department, business informatics faculty, The National Research University - Higher School of Economics/HSE (master program "Software engineering").
It is a part of special subject curricula unit, and it is delivered in modules 3-4 of the first academic year. The course length is ***80*** academic hours of audience classes divided into ***40*** lecture hours and ***40*** seminar hours and ***100*** academic hours for students self-study.
The covered number of credits is ***5***. Academic control forms are one home assignment, one test, and one written exam after module 4.

Pre-requisites

The course is based on the knowledge of foundations of discrete mathematics, computer science, automata theory and computer programming.

Course Objective

The interest in business process management systems is a rapidly growing. It has become evident that information systems need to be driven by processes and not just data. Moreover, the importance of link between business process analysis and redesign on the one hand and enterprise information systems on the other hand is evident. Process-aware information systems are used by large organizations all over the world and in many different sectors (banks, insurance companies, governments, manufacturers, service providers, travel agencies, electronic stores, etc. etc.).

Today, there is a lot of attention for business process management systems, both in practice and academia. Note that leading software companies such as SAP, IBM, Microsoft, and Oracle are heavily investing in business process management technology. As an engineers working in practice, students will often work on the interface between business processes and IT. Moreover, there are many academic and intellectual challenges as enterprise wide systems are much more complex than the software found in isolated applications or technical devices.

Abstract

Information systems have become the backbone of most organizations. Organizations such as banks, tax authorities, online travel agencies, and electronic shops can be considered as IT companies, where informational systems play the central role.

A business process describes the flow of work within an organization. This flow of work is supported and managed by an informational system. This course introduces the basic concepts of workflow management. The emphasis is on modeling workflow processes and the characteristics of contemporary workflow management.

Workflow processes are a specific type of operational processes typically associated with work processes in administrative environments. However, any case-driven operational process falls in this category. Workflow technology provides the functionality to support these processes. Since this technology is adopted in many enterprise information systems

knowledge about these systems and experience in making and enacting workflow models is relevant for students in software engineering.

Process-aware information systems, such as workflow management systems, enterprise resource planning (ERP) systems, customer relationship management (CRM) systems, and product data management (PDM) systems, are generic information systems that are configured on the basis of process models. In some systems, the process models are explicit and can be adapted (e.g., the control flow in a workflow system) while in other systems they are implicit (e.g., the reference models in the context of SAP). In some systems, they are hard-coded and in other systems truly configurable. However, it is clear that in any enterprise, business processes and information systems are strongly intertwined. Therefore, it is important that students understand the relationships between systems and processes and are able to model complex systems involving processes, humans, and organizations.

The development of enterprise information systems is challenging. These systems are complex and possess concurrency and nondeterminism. Thus it is rather difficult for a human to envision all possible executions of workflow. This makes business process systems error prone and difficult to design and configure. As a result, enterprise information systems may have malfunctions and poor performance. The solution is to move from traditional focus on data modeling to paying more attention to business processes these systems support and to use special formalisms for modeling and analysis (verification) of workflow processes.

The formalism used in this course is high-level Petri nets as supported by CPN Tools. *Petri nets* is a popular formalism for modeling, analyzing and verifying reactive and distributed systems. Their strength are in their simple but precise semantics, their clear graphical notation, and many methods and algorithms for analysis and verification. Petri nets provide the basic primitives for modeling concurrency, communication, and synchronization. The extension of the basic model with data (colors), time, and hierarchy (module structure) makes it possible to module and analyze complex artifacts in enterprise information systems.

CPN Tools was developed in Aarhus, Denmark. CPN Tools supports editing, simulation, state-space analysis, and performance analysis of colored Petri nets – a popular class of high-level Petri nets. CPN Tools is used as a tool to test ideas, to do simple simulations and other forms of analysis, and to construct basic prototypes. Students can quickly model simple systems and business processes to test their understanding of the main concepts. In the sequel they can use CPN Tools to model more complex information systems and evaluate them using interactive simulation and state-space analysis. It is also possible to compare different business process designs.

The first part of the course focuses on transforming informal descriptions of business processes and systems into high-level Petri nets. Given an informal description, students should be able to map the control-flow perspective onto high-level Petri nets. Also mappings of the other perspectives (e.g., data, resources, organization, and applications) onto abstractions understandable by computer programs are considered. In addition, students are exposed to industrial languages such as UML AD, UML SC, UML SD, UML CD, EPCs, and BPMN. Moreover, participants need to model and implement non-trivial workflows in a specific workflow management system YAWL. It should be noted that although the focus is on pure workflow management systems, the knowledge and experience obtained by students will be also applicable to other process-aware information systems.

The second part of the course focuses on the analysis of workflows. Some attention is given to the simulation of workflow with the goal of improving them. One of the main topics in the second parts will be workflow verification, i.e., How to automatically identify design errors and correct them? Here different tools are being used and, among others, the SAP reference model and its errors are used as examples. This requires an introduction to concepts such as WF-nets, various soundness notions, free-choice nets, reduction rules, etc. Another topic is

process mining, i.e., analyzing workflow processes based on their event logs. Here synthesis techniques are used to discover Petri nets from event data.

All of this is put into the context of characteristic classes of information systems (e.g., workflow management systems and ERP systems).

Training Objectives:

After taking this course the student should have achieved the following objectives:

- Knows the characteristics of workflow processes, workflow management systems and groupware.
- Is able to make a workflow model based on an informal description.
  Can apply concepts such as case, task, work item, activity, role, organizational unit, resource, push, pull, etc.
- Knows the reference architecture of workflow systems and is aware of the basic functionality offered by contemporary systems.
- Can analyze a workflow process (validation, verification, and performance analysis).

II. Topic-Wise Curricula Plan

No	Topic Name	Course Hours, Total	Audience Hours		Self-Study
			Lectures	Practical Studies	
Module 3 (90 hrs.)					
1.	Introduction Business Process Management.	28	4	4	10
2.	Workflow modeling: Modeling the process perspective.	36	8	8	20
3.	Workflow modeling: Modeling the organizational perspective (including link to groupware).	28	4	4	10
4.	Workflow modeling: Modeling the other perspectives (including link to document management).	28	4	4	10
	Module 3, totally:	90	20	20	50
Module 4 (90 hrs.)					
5.	Process-aware information systems: Workflow management technology.	18	4	4	10
6.	Methods to support workflow (re)design.	18	4	4	10
7.	Business process analysis and verification.	28	6	6	16
8.	Languages and standards.	18	4	4	10

9.	Perspectives of business process management systems.	8	2	2	4
	Module 4, totally:	90	20	20	50
	TOTAL:	180	40	40	100

III. Basic book(s) and/or reader(s)

Books:

1. ван дер Аалст В., ван Хей К. Управление потоками работ: модели, методы и системы. – М.: Физматлит, 2007. – 316 с.
2. Aalst, W.M.P. van der, Stahl C. Modeling business processes: a Petri net-oriented approach. Cambridge: The MIT Press, 2011. – 386 p.
3. Cardoso, J., Aalst, W.M.P. van der (Eds.).(2009). *Handbook of research on business process modeling*. Hershey PA: Information Science Reference, 607 pp.
4. Jensen, K., Aalst, W.M.P. van der (Eds.).(2009). *Transactions on Petri Nets and other models of concurrency II : special issue on concurrency in process-aware information systems*. Berlin: Springer, 295 pp.
5. Hofstede, A.H.M. ter, Aalst, W.M.P. van der, Adams, M., Russell, N.C. (Eds.).(2010). *Modern business process automation : YAWL and its support environment*. Berlin: Springer, 676 pp.
6. Ломазова И.А. Сети Петри и анализ поведенческих свойств распределенных систем. – Ярославль: ЯрГУ, 2002. 164 с.
7. Jensen K. and Kristensen L. M. Coloured Petri Nets Modelling and Validation of Concurrent Systems, Springer-Verlag, 2009.
8. C. Girault, R. Valk. Petri Nets for Systems Engineering: A Guide to Modeling, Verification, and Applications. Springer-Verlag, 2002.

Internet References:

1. Internet resource: The Petri Nets World http://www.informatik.uni-hamburg.de/TGI/PetriNets/
2. Internet resource: Workflow management coalition http://www.wfmc.org/
3. Internet resource: Workflow And Reengineering International Association http://www.waria.com/
4. Carl Adam Petri and Wolfgang Reisig. Petri net. *Scholarpedia*, 3(4):6477 (2008). http://www.scholarpedia.org/article/Petri_net

IV. Education control forms / Assessments:

- Current control: attendance record, seminar-based knowledge control, home assignment control;
- Intermediate control: written test by the end of Module 3, home assignment by the end of Module 4;
- Final control: exam by the end of Module 4;
- The final course grade is formed from the following elements:
1) practice activities (reports, discussions, business cases);
2) home assignment;
3) written test;
4) exam at the end of Module 4.

The overall course grade *G* (10-point scale) is calculated as follos:

$$CG = 0{,}3\,P + 0{,}3\,H + 0{,}4\,T,$$

$$G = 0{,}4\,CG + 0{,}6\,E,$$

where *CG* is the cumulative grade at the end of Module 4, *P* – practice activity in the course of Modules 3 and 4, *H* is the homework grade, *E* – exam at the end of Module 4 (all in 10-point scale).

The overall course grade *G* (10-point scale) is rounded up to an integer number of points.

Summary Table : Correspondence of ten-point to five-point system's marks

Ten-point scale [10]	Five-point scale [5]
1 – unsatisfactory 2 – very bad 3 – bad	Unsatisfactory – 2
4 – satisfactory 5 – quite satisfactory	Satisfactory – 3
6 – good 7 – very good	Good – 4
8 – nearly excellent 9 – excellent 10 – brilliant	Excellent – 5

V. Program Contents

Topic 1: Introduction Business Process Management.

- *Topic outline:*
  - Ontology for workflow management.
  - Work.
  - Business processes.
  - Allocating and accepting work.
  - Organizational structures.
  - Managing processes.

- Information systems for business processes.
- Course overview.

♦ *Main references/books/reading:*

1. ван дер Аалст В., ван Хей К. Управление потоками работ: модели, методы и системы. – М.: Физматлит, 2007. – 316 с.
2. Aalst, W.M.P. van der, Stahl C. Modeling business processes: a Petri net-oriented approach. Cambridge: The MIT Press, 2011. – 386 p.

♦ *Additional references/books/reading:*

1. Hofstede, A.H.M. ter, Aalst, W.M.P. van der, Adams, M., Russell, N.C. (Eds.).(2010). Modern business process automation : YAWL and its support environment. Berlin: Springer, 676 pp.
2. Internet resource: Workflow management coalition http://www.wfmc.org/
3. Internet resource: Workflow And Reengineering International Association http://www.waria.com/

Topic 2. Workflow modeling: Modeling the process perspective.

♦ *Topic outline:*

- Workflow concepts.
- The case.
- The task.
- The process.
- Routing.
- Enactment.
- Petri nets. Classical Petri nets.
- High-level Petri nets.
- Mapping workflow concepts onto Petri nets: the process, routing, enactment.
- Examples.

♦ *Main references/books/reading:*

1. ван дер Аалст В., ван Хей К. Управление потоками работ: модели, методы и системы. – М.: Физматлит, 2007. – 316 с.
2. Aalst, W.M.P. van der, Stahl C. Modeling business processes: a Petri net-oriented approach. Cambridge: The MIT Press, 2011. – 386 p.
3. Jensen K. and Kristensen L. M. Coloured Petri Nets Modelling and Validation of Concurrent Systems, Springer-Verlag, 2009.

♦ *Additional references/books/reading:*

1. Ломазова И.А. Сети Петри и анализ поведенческих свойств распределенных систем. – Ярославль: ЯрГУ, 2002. 164 с.
2. C. Girault, R. Valk. Petri Nets for Systems Engineering: A Guide to Modeling, Verification, and Applications. Springer-Verlag, 2002.

3. Jensen, K., Aalst, W.M.P. van der (Eds.).(2009). *Transactions on Petri Nets and other models of concurrency II : special issue on concurrency in process-aware information systems*. Berlin: Springer, 295 pp.
4. Internet resource: The Petri Nets World http://www.informatik.uni-hamburg.de/TGI/PetriNets/
5. Carl Adam Petri and Wolfgang Reisig. Petri net. *Scholarpedia*, 3(4):6477 (2008). http://www.scholarpedia.org/article/Petri_net
6. Вирбицкайте И.Б. Сети Петри: модификации и расширения. Новосибирск: Изд-во НГУ, 2005, 123 с.
7. В.Е.Котов. Сети Петри. М.: Наука, 1984.
8. Ломазова И.А. Вложенные сети Петри: моделирование и анализ распределенных систем с объектной структурой. – М.: Научный мир, 2004. 208 с.
9. Питерсон Дж. Теория сетей Петри и моделирование систем. М.: Мир, 1984.

Topic 3. Workflow modeling: Modeling the organizational perspective (including link to groupware).

- *Topic outline:*
  - Modeling causality relations and resource dependencies with Petri nets.
  - Resource management concepts.
  - The resource.
  - Resource classification.
  - Allocating activities to resources.
  - Resource management in more detail: allocation principles.
  - Improving workflows.
  - Bottlenecks in the workflow.
  - Business process re-engineering.
  - Guidelenes for (re)designing workflows.
- *Main references/books/reading:*

1. ван дер Аалст В., ван Хей К. Управление потоками работ: модели, методы и системы. – М.: Физматлит, 2007. – 316 с.
2. Aalst, W.M.P. van der, Stahl C. Modeling business processes: a Petri net-oriented approach. Cambridge: The MIT Press, 2011. – 386 p.

- *Additional references/books/reading:*

1. Hofstede, A.H.M. ter, Aalst, W.M.P. van der, Adams, M., Russell, N.C. (Eds.).(2010). Modern business process automation : YAWL and its support environment. Berlin: Springer, 676 pp.
2. Cardoso, J., Aalst, W.M.P. van der (Eds.).(2009). *Handbook of research on business process modeling*. Hershey PA: Information Science Reference, 607 pp.
3. Internet resource: Workflow management coalition http://www.wfmc.org/

4. Internet resource: Workflow And Reengineering International Association http://www.waria.com/

Topic 4. Workflow modeling: Modeling the other perspectives (including link to document management).

- *Topic outline:*
  - Role of workflow management systems.
  - How information systems are traditionally structured.
  - Separation of management and execution. Advantages.
  - Workflow management software.
  - A reference model.
  - Workflow enactment service.
  - Process definition tools.
  - Workflow client applications.
  - Invoked applications.
  - Other workflow enactment services.
  - Administration and monitoring tools.
  - Roles of people involved.
  - Storage and exchange of data.
  - Data in a workflow system.
  - Interfacing problems.
  - Interoperability standards.
  - Required technical infrastructure.
- *Main references/books/reading:*
  1. ван дер Аалст В., ван Хей К. Управление потоками работ: модели, методы и системы. – М.: Физматлит, 2007. – 316 с.
  2. Aalst, W.M.P. van der, Stahl C. Modeling business processes: a Petri net-oriented approach. Cambridge: The MIT Press, 2011. – 386 p.
- *Additional references/books/reading:*
  1. Hofstede, A.H.M. ter, Aalst, W.M.P. van der, Adams, M., Russell, N.C. (Eds.).(2010). Modern business process automation : YAWL and its support environment. Berlin: Springer, 676 pp.
  2. Cardoso, J., Aalst, W.M.P. van der (Eds.).(2009). *Handbook of research on business process modeling*. Hershey PA: Information Science Reference, 607 pp.
  3. Internet resource: Workflow management coalition http://www.wfmc.org/
  4. Internet resource: Workflow And Reengineering International Association http://www.waria.com/

Topic 5. Process-aware information systems: Workflow management technology.

- *Topic outline:*
  - Development methods.
  - Why a specific method for WFM?
  - Business process re-engineering.
  - Rapid application development.
  - The 'IPSD' method.
  - Basic principles.
  - Preparation.
  - Diagnosis.
- *Main references/books/reading:*
  1. ван дер Аалст В., ван Хей К. Управление потоками работ: модели, методы и системы. – М.: Физматлит, 2007. – 316 с.
  2. Aalst, W.M.P. van der, Stahl C. Modeling business processes: a Petri net-oriented approach. Cambridge: The MIT Press, 2011. – 386 p.
- *Additional references/books/reading:*
  1. Hofstede, A.H.M. ter, Aalst, W.M.P. van der, Adams, M., Russell, N.C. (Eds.).(2010). Modern business process automation : YAWL and its support environment. Berlin: Springer, 676 pp.
  2. Cardoso, J., Aalst, W.M.P. van der (Eds.).(2009). *Handbook of research on business process modeling*. Hershey PA: Information Science Reference, 607 pp.
  3. Internet resource: Workflow management coalition http://www.wfmc.org/
  4. Internet resource: Workflow And Reengineering International Association http://www.waria.com/

Topic 6. Methods to support workflow (re)design.

- *Topic outline:*
  - Process redesign.
  - Requirements.
  - Architecture.
  - Component design.
  - Construction.
  - Integration.
  - Delivery.
  - Enactment.
  - Monitor and improve.
  - Integrating WFMS with legacy systems.
- *Main references/books/reading:*

1. ван дер Аалст В., ван Хей К. Управление потоками работ: модели, методы и системы. – М.: Физматлит, 2007. – 316 с.
2. Aalst, W.M.P. van der, Stahl C. Modeling business processes: a Petri net-oriented approach. Cambridge: The MIT Press, 2011. – 386 p.

- *Additional references/books/reading:*

1. Hofstede, A.H.M. ter, Aalst, W.M.P. van der, Adams, M., Russell, N.C. (Eds.).(2010). Modern business process automation : YAWL and its support environment. Berlin: Springer, 676 pp.
2. Cardoso, J., Aalst, W.M.P. van der (Eds.).(2009). *Handbook of research on business process modeling*. Hershey PA: Information Science Reference, 607 pp.
3. Internet resource: Workflow management coalition http://www.wfmc.org/
4. Internet resource: Workflow And Reengineering International Association http://www.waria.com/

Topic 7. Business process analysis and verification.

- *Topic outline:*
  - Analysith techniques.
  - Reachability analysis.
  - Structural analysis.
  - Soundeness.
  - Method with computer support.
  - Method without computer support.
  - Performance analysis.
  - Capacity planning.
  - Method to calculate capacity requirements.
  - Some basic queuieing theory to take variability into account.
- *Main references/books/reading:*

1. ван дер Аалст В., ван Хей К. Управление потоками работ: модели, методы и системы. – М.: Физматлит, 2007. – 316 с.
2. Aalst, W.M.P. van der, Stahl C. Modeling business processes: a Petri net-oriented approach. Cambridge: The MIT Press, 2011. – 386 p.

- *Additional references/books/reading:*

1. Hofstede, A.H.M. ter, Aalst, W.M.P. van der, Adams, M., Russell, N.C. (Eds.).(2010). Modern business process automation : YAWL and its support environment. Berlin: Springer, 676 pp.
2. Cardoso, J., Aalst, W.M.P. van der (Eds.).(2009). *Handbook of research on business process modeling*. Hershey PA: Information Science Reference, 607 pp.
3. Internet resource: Workflow management coalition http://www.wfmc.org/
4. Internet resource: Workflow And Reengineering International Association http://www.waria.com/

Topic 8. Languages and standards.

- *Topic outline:*
  - Current generation of workflow products.
  - Staffware.
  - COSA.
  - ActionWorkflow.
  - Analysis tools.
  - BPR tools.
  - Selecting a workflow management system.
  - Adaptive workflow.
  - Wordflow management and CSCW.
  - Classification of change.
- *Main references/books/reading:*
  1. ван дер Аалст В., ван Хей К. Управление потоками работ: модели, методы и системы. – М.: Физматлит, 2007. – 316 с.
  2. Aalst, W.M.P. van der, Stahl C. Modeling business processes: a Petri net-oriented approach. Cambridge: The MIT Press, 2011. – 386 p.
- *Additional references/books/reading:*
  1. Hofstede, A.H.M. ter, Aalst, W.M.P. van der, Adams, M., Russell, N.C. (Eds.).(2010). Modern business process automation : YAWL and its support environment. Berlin: Springer, 676 pp.
  2. Cardoso, J., Aalst, W.M.P. van der (Eds.).(2009). *Handbook of research on business process modeling*. Hershey PA: Information Science Reference, 607 pp.
  3. Internet resource: Workflow management coalition http://www.wfmc.org/
  4. Internet resource: Workflow And Reengineering International Association http://www.waria.com/

Topic 9. Perspectives of business process management systems.

- *Topic outline:*
  - Workflow management in the future.
  - Modeling.
  - Analysis.
  - Planning.
  - Transaction management.
  - Interoperability.
  - Internet/Intranet.
  - Logistical management.

- *Main references/books/reading:*

1. ван дер Аалст В., ван Хей К. Управление потоками работ: модели, методы и системы. – М.: Физматлит, 2007. – 316 с.
2. Aalst, W.M.P. van der, Stahl C. Modeling business processes: a Petri net-oriented approach. Cambridge: The MIT Press, 2011. – 386 p.

- *Additional references/books/reading:*

1. Hofstede, A.H.M. ter, Aalst, W.M.P. van der, Adams, M., Russell, N.C. (Eds.).(2010). Modern business process automation : YAWL and its support environment. Berlin: Springer, 676 pp.
2. Cardoso, J., Aalst, W.M.P. van der (Eds.).(2009). *Handbook of research on business process modeling*. Hershey PA: Information Science Reference, 607 pp.
3. Internet resource: Workflow management coalition http://www.wfmc.org/
4. Internet resource: Workflow And Reengineering International Association http://www.waria.com/

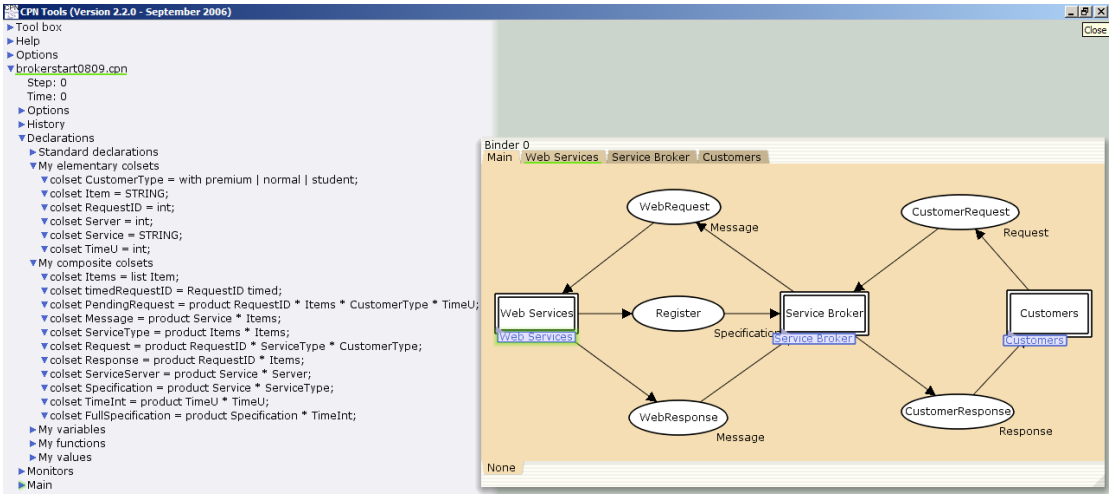
VI. Assignment topics for various education control forms:

- **Home assignment:**

The goal is to write a report and to hand in some models made using CPN Tools.
We give an *example* of a home assignment.

The setting of the assignment is a service broker that interacts with several web services to handle service requests from customers. The services (both the customer requests and the provided web services) are of the type: produce certain items from certain given items. The service requested by the customer may not immediately match with one of the given services, so the broker may need to combine several web services.

Part of the model is already given in CPN Tools. The top level is shown below.



The top level of the model contains three components: Web Services, Service Broker and Customers. The interface places of these components are given and are not to be changed for any

part of the assignment. For the Web services and the Customers a preliminary model is given, but they need to be modified in some of the subtasks.

The Customers component models a series of customers that send a service Request to the Service Broker, and afterwards expect a service Response. A request consists of a request ID, a service type, and a customer type. A response consists of a request ID and the requested items as specified by the service type.

The Web Services component models a set of web services that first register themselves at the service broker, and then send a response to every request. This component mainly communicates in terms of a Message, which consists of the name of the web service that sends or receives the message, and some items.

The Service Broker component is supposed to act as an intermediary between the web services and the customers. Apart from interacting with the web services, the broker also needs to determine which web services can and need to be used.

An important concept in this setting is the notion of a service type. A service type consists of two series of items, corresponding to inputs and outputs respectively. For example, the following two service types correspond to a taxi reservation service and a yellow pages service respectively:

(["Address", "DateTime"], ["TaxiReservation"])
(["RestaurantName"], ["Address"])

E.g., given the name of a restaurant, the second service provides its address.

On the other hand, a customer may want to use a service type like the following:

(["RestaurantName", "DateTime"], ["TaxiReservation"])

Using the two mentioned web services, the broker can respond to such a request of a customer. For example, it can use the yellow pages to determine the address of the given restaurant, as its name is given. Together with the given date and time, the taxi reservation service can then be used to reserve a taxi.

In this assignment we abstract from the values of the items and just refer to their types. The following color sets and variables are given:

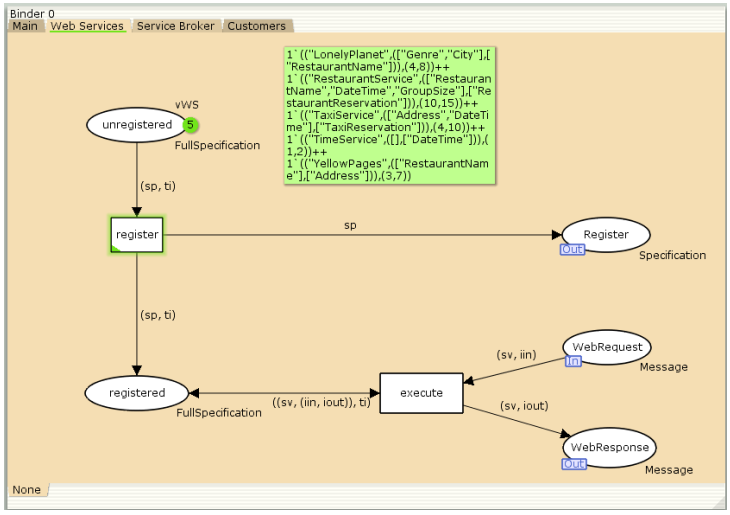
```
CPN Tools (Version 2.2.0 - September 2006)
Declarations
  Standard declarations
  My elementary colsets
    colset CustomerType = with premium | normal | student;
    colset Item = STRING;
    colset RequestID = int;
    colset Server = int;
    colset Service = STRING;
    colset TimeU = int;
  My composite colsets
    colset Items = list Item;
    colset timedRequestID = RequestID timed;
    colset PendingRequest = product RequestID * Items * CustomerType * TimeU;
    colset Message = product Service * Items;
    colset ServiceType = product Items * Items;
    colset Request = product RequestID * ServiceType * CustomerType;
    colset Response = product RequestID * Items;
    colset ServiceServer = product Service * Server;
    colset Specification = product Service * ServiceType;
    colset TimeInt = product TimeU * TimeU;
    colset FullSpecification = product Specification * TimeInt;
  My variables
    var ct: CustomerType;
    var i: Item;
    var iin,iout: Items;
    var id: RequestID;
    var rq: Request;
    var st: ServiceType;
    var sp: Specification;
    var sr: Server;
    var sv: Service;
    var tu:TimeU;
    var ti: TimeInt;
  My functions
    fun fdelay ((lb,ub):TimeInt)=discrete(lb,ub);
    fun Mtime () = IntInf.toInt(time()):int;
  My values
    val vCT = 1`premium ++ 3`normal ++ 2`student;
    val vServers = [1,2,3,4,5]
    val vSS = [
       ("TimeService", 1),
       ("TimeService", 3),
       ("TaxiService", 2),
       ("TaxiService", 5),
       ("YellowPages", 3),
       ("YellowPages", 5),
       ("RestaurantService",4),
       ("LonelyPlanet", 1)
     ]
    val vST= [
       (["Address"], ["TaxiReservation"]),
       (["RestaurantName", "DateTime", "GroupSize"],["RestaurantReservation", "TaxiReservation"]),
       (["Genre", "City", "DateTime"], ["TaxiReservation"]),
       (["Genre", "City", "GroupSize"],["TaxiReservation", "RestaurantReservation"])
     ];
    val vWS = [
       (("TimeService", ([], ["DateTime"])), (1,2)),
       (("TaxiService", (["Address", "DateTime"], ["TaxiReservation"])), (4,10)),
       (("YellowPages", (["RestaurantName"], ["Address"])), (3,7)),
       (("RestaurantService", (["RestaurantName", "DateTime", "GroupSize"], ["RestaurantReservation"])), (10,15)),
       (("LonelyPlanet", (["Genre", "City"], ["RestaurantName"])), (4,8))
     ];
```

The Web Services component models a set of web services. Internally, each web service is specified using a specification (FullSpecification) like

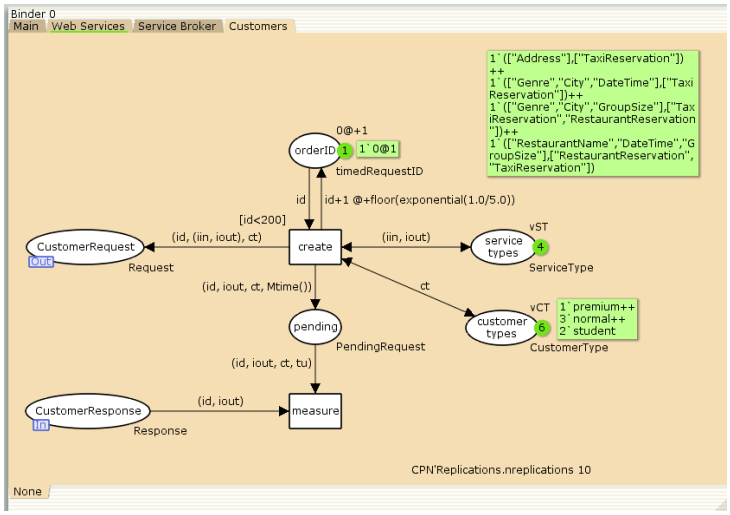
("LonelyPlanet", (["Genre", "City"], ["RestaurantName"]), (4,8))

This means that there is a service called "LonelyPlanet", which provides an item "RestaurantName" if the items "Genre" (style of food) and "City" are given. The service time is from the interval 4 to 8 seconds (uniform distribution).

Each web service first registers itself at the service broker, but it does not provide information about its service time. Afterwards it sends a response to each request. The given model is incomplete as, e.g., it does not take into account the service time. The subnet Web Services is shown below:

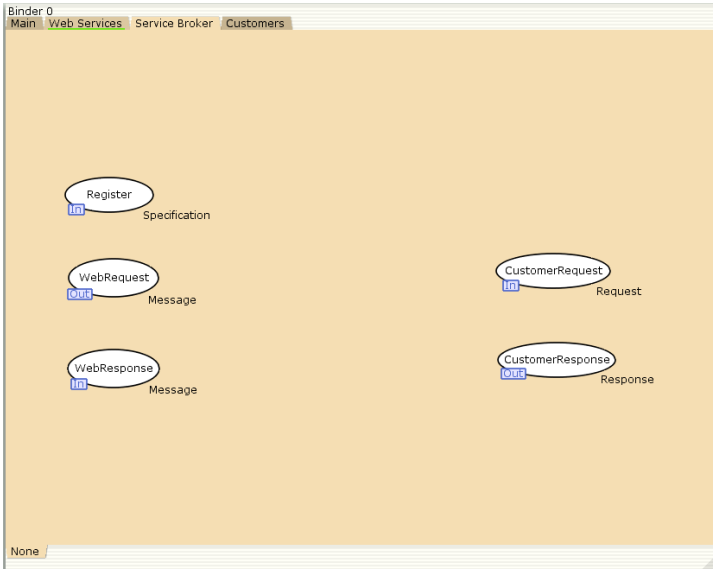


The customers send requests that consist of a request ID, a service type, and a customer type. Regarding the service type, the first series of items are provided by the customer, and the second series of items are requested. In turn the customer expects a response that consists of the request ID, and the requested items. There are several types of customers (see the example value *vCT*), and some pose more requests than others (1 premium to 3 normal to 2 student). Each service type (see the example value *vST*) consists of some given items, and some expected items. The requests are submitted by customers according to a Poisson arrival process, with on average 5 seconds between any two subsequent requests. The subnet Customers is shown below:



The transition *measure* is used by so-called monitors to measure statistics. These are stored in the subdirectory "Output" if a single run is simulated. Multiple subruns are needed (use CPN'Replications.nreplications 10), and these are stored in subdirectory "Reps_X".

The initial challenge of the assignment is to complete the remaining service broker sub process. The service broker determines the web services that are needed for responding to the customer's requests, and the broker performs the required interaction.



Important: In the various tasks we will study slightly different rules and assumptions for the broker. Your solutions should be *generic*, i.e., it should be easy to support other Web Services that register themselves at the Service Broker, and other requests posed by the Customers. In other words: the solution should not depend on a particular value of the constants *vST* and *vWS*. The following assumptions apply to each task:

- Each web service generates a single item.
- Each item can be generated by at most one web service.
- The set of given web services contains no mutual dependencies (i.e., to generate an item using some web services, the item itself cannot be a pre-requisite).

  Based on the initial model, please, provide the following CPN models and include a description of the model and your findings in a report (word or pdf). Test your models by using different service types, both for the web services and the customers, i.e., show that by using completely different values of vST and vWS another service broker can be simulated without changing anything else. Show in your report at least two non-trivial instantiations which have been used for testing your solution.

Task 1

Provide a CPN model that describes the service broker. The following restrictions should be applied:

- The broker must ensure that at any time only one customer is being served.
- Every customer request can be handled using the provided web services.
- Items correspond to real goods that are to be used exactly once.

In this task we consider items as real goods. Within each single customer request, every available item (i.e., the ones provided by the customer and the ones generated using a web service) should be used exactly once. In particular, duplicates in any list of items matter in this setting. Notice that the example set of request types *vST* must be restricted to those that can be handled using this interpretation.

Provide the model as a CPN file labeled "task1.cpn". In the report briefly describe the model and your design choices. Include a READABLE diagram of the corresponding CPN.

Task 2

Provide a CPN model for another service broker. The following restrictions should be applied:

- The broker must ensure that at any time only one customer is being served.
- Every customer request can be handled using the provided web services, after adding any missing items.
- Items correspond to real goods that are to be used exactly once.

In this task we continue to consider items as real goods. However, it is no longer guaranteed that every customer request can be handled using the provided web services, as some items may be missing. The broker should detect the items (if any) that are missing, and log them in a place within the broker (one entry for each request where items are missing). Moreover, the broker does not want to be impolite to the customer, and hence the broker tries to provide the missing required items himself.

For each value of *vST* and *vWS* that you use to test your model, indicate which items (if any) are missing for which service type in *vST*.

Provide the model as a CPN file labeled "task2.cpn". In the report briefly describe the model and your design choices. Include a READABLE diagram of the corresponding CPN.

Task 3

Provide a CPN model for another service broker. The following restrictions should be applied:

- The broker must ensure that at any time only one customer is being served.
- Every customer request can be handled using the provided web services.
- Items correspond to data that can be used any number of times.

In this task we consider items as data. Within each single customer request, every item (both the ones provided by the customer and the ones generated using a web service) can be used any number of times. So, some items may be used more than once, and others may not be used at all. As data items can be reused within a single customer request, make sure that the broker minimizes the communication with the used web services.

Provide the model as a CPN file labeled "task3.cpn". In the report briefly describe the model and your design choices. Include a READABLE diagram of the corresponding CPN.

Task 4

Provide a CPN model that describes the web services in such a way that the service times are taken into account. In addition, consider a set of physical servers (see the example value *vServers*) that execute the services. Some services are installed on the same server, and some services can be offered by different servers. Assume that, at any time, on each server at most one web service may be active on a service request. The relation between services and servers can be specified using a set of tuples of a service and the server (see the example value *vSS*).

Also analyze the flow time as observed by the (different types of) customers. In this task, use the broker model from task 3.

Provide the model as a CPN file labeled "task4.cpn". In the report briefly describe the model and your design choices. Include a READABLE diagram of the corresponding CPN. Also analyze the flow times and present the results. The analysis of flow times should be based on running at least 10 subruns of at least 200 service request.

Task 5

Provide a CPN model for another service broker. The following restrictions should be applied:

- The broker must ensure that at any time up to 10 customers are being served.
- Every customer request can be handled using the provided web services.
- Items correspond to data that can be used any number of times.

In this task we continue to consider items as data. However, it should now be possible to handle a number of customer requests in parallel. Make sure that requests to the web services are handled in parallel whenever possible.

Also analyze the flow time as observed by the (different types of) customers. In this task, use the web services model from task 4. Compare these flow times with the ones obtained in task 4.

Provide the model as a CPN file labeled "task5.cpn". In the report briefly describe the model and your design choices. Include a READABLE diagram of the corresponding CPN. Also analyze the flow times and present the results.

Task6

Provide a CPN model for another service broker. The following restrictions should be applied:

- The broker must ensure that at any time up to 10 customers are being served.
- Every customer request can be handled using the provided web services.
- Items correspond to data that can be used any number of times.

In this task we continue to consider items as data, and to handle some customer requests in parallel. In addition, the service broker should take into account that some customers are premium customers that pay a higher subscription fee. That is, premium customers have priority over normal customers, and normal customers have priority over student customers that hold a free subscription. Priorities can be taken into account at two places in the broker: when accepting new customer requests, and when sending a message to a web service. Do not impose any unnecessary order on requests for customers of the same type.

For the different (combinations of) places where priorities play a role, analyze the flow time as observed by the different types of customers. In this task, use the web services model from task 4. Compare these flow times with the ones obtained in tasks 4 and 5.

Provide the model as a CPN file labeled "task6.cpn".
In the report briefly describe the model and your design choices. Include a READABLE diagram of the corresponding CPN. Also analyze the flow times and present the results.

- **Written test**

The written test is a computer testing assessment based on the topics covered in the third module.

- **Exam**

The final exam is a computer testing assessment based on the course topics.

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