

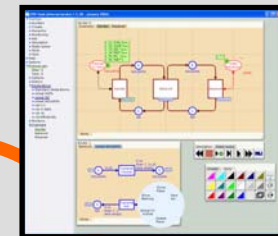
# Teaching Modelling and Validation of Concurrent Systems using Coloured Petri Nets

Lars M. Kristensen  
Kurt Jensen

Department of Computer Science  
University of Aarhus  
DENMARK

{lmkristensen,kjensen}@daimi.au.dk

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- **LO1** explain(4) the constructs and concepts in the CPN modelling language.
- **LO2** define(2) and explain(4) the syntax and semantics of CPNs.
- **LO3** define(2) and explain(4) properties for characterising the behaviour of concurrent systems.
- **LO4** explain(4) the basic concepts and techniques underlying state space analysis methods.
- **LO5** apply(4) CPNs and CPN Tools for modelling and validation of smaller concurrent systems.
- **LO6** judge(4) the practical application of CPNs for modelling and validation of concurrent systems.



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# Course Overview

- The overall aim is for the participants to learn:
  - **Why** modelling and validation of systems is beneficial.
  - **When** to apply modelling and validation to systems.
  - **How** to conduct modelling and validation of systems.
- Emphasis is on a concrete modelling language (Coloured Petri Nets) and supporting computer tools (CPN Tools).
- Prerequisites are two short introductory programming courses (10 ECTS), course on discrete mathematics.
- 20-30 participants usually in their 3rd-5th year of study.



# Course Organisation

- Spans two teaching periods (~ 10 ECTS).
- **First Quarter (Q1) - 7 weeks (5 ECTS):**
  - CPN modelling language constructs.
  - Simulation, state space analysis, performance analysis.
  - Two smaller practical projects.
  - Oral exam (20 minutes) with no advance preparation.
- **Second Quarter (Q2) - 7 weeks (5 ECTS):**
  - Larger project on CPN modelling and validation.
  - Project report (~ 15-20 pages).
  - Oral exam (20 minutes) based on the project and project report.



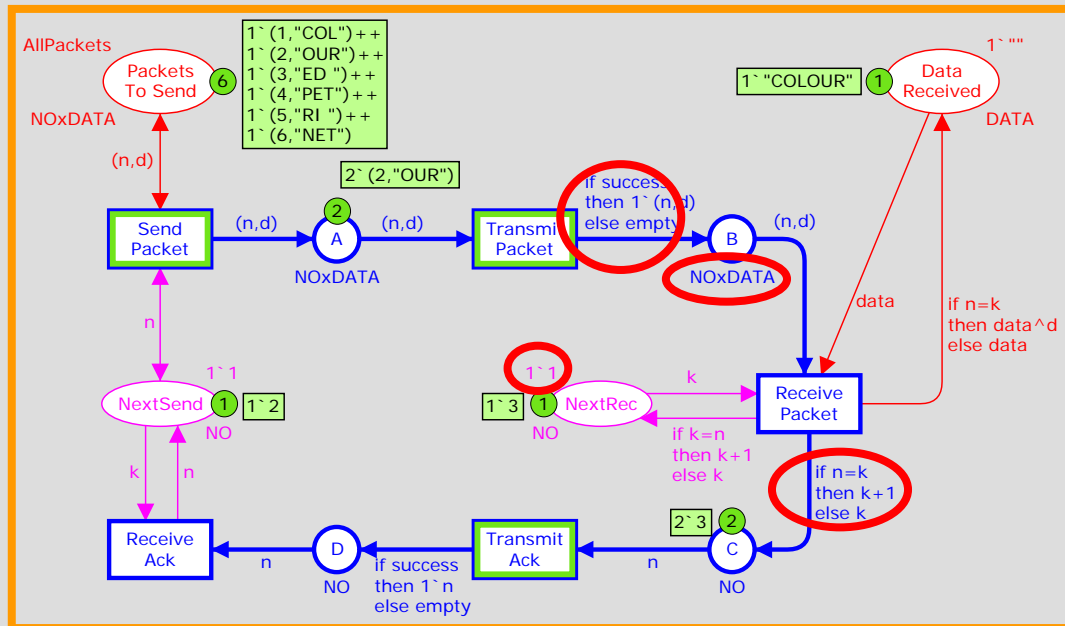
# Outline of this Talk

- **Coloured Petri Nets and the teaching material**
- **First quarter:**
  - Intended learning outcomes
  - Teaching methods
- **Second quarter:**
  - Intended learning outcomes
  - Teaching methods
  - Project example
- **Summary and conclusions**



# Coloured Petri Nets

- Graphical modelling language for concurrent systems.
- Combination of Petri Nets and programming language:



## Petri Nets:

concurrency  
control structures  
synchronisation  
communication

## CPN ML (Standard ML):

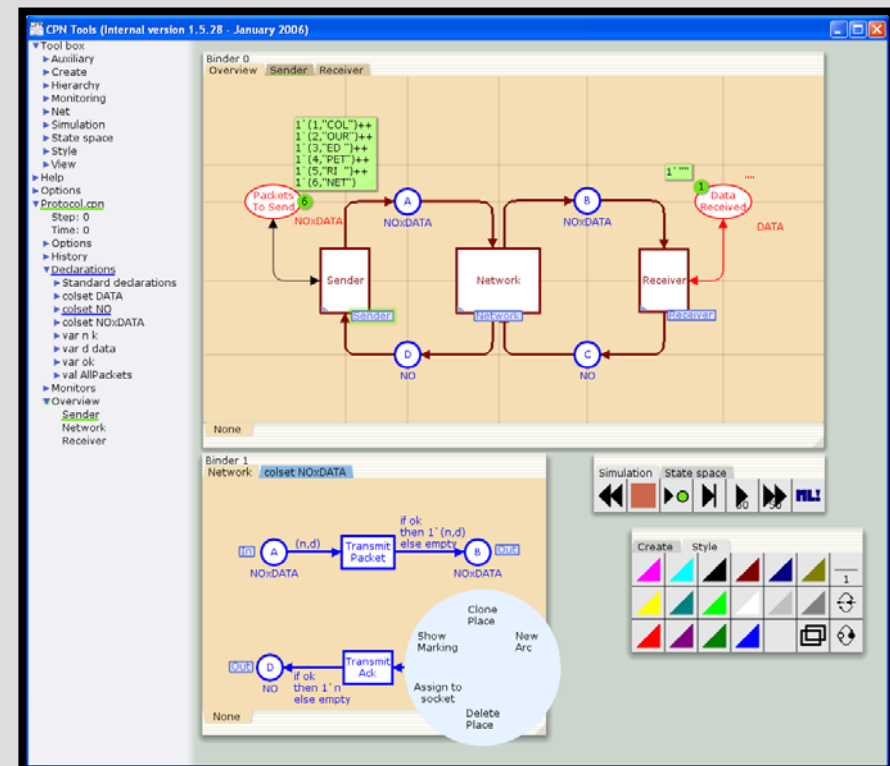
data manipulation  
compact modelling  
parameterisation

- Includes a hierarchical module concept and a time concept.
- Simulation, state space analysis, and performance analysis.



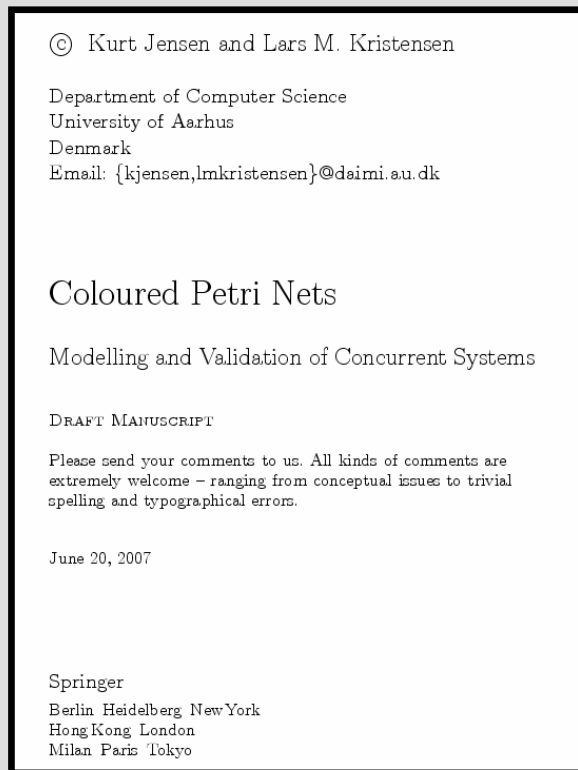
# CPN Tools [\[www.daimi.au.dk/CPNTools\]](http://www.daimi.au.dk/CPNTools)

- **Modelling and validation of Coloured Petri Nets are supported by CPN Tools.**
- **Main Features:**
  - Editing and syntax check.
  - Interactive- and automatic simulation.
  - State space analysis.
  - Performance analysis.
  - Domain specific behavioural visualisation.
- **License available free of charge.**



# Teaching Material

- The course has been developed in parallel with a new textbook on Coloured Petri Nets:



## Part 1: Coloured Petri Nets

- Basic concepts
- CPN ML programming
- Hierarchical models
- Timed models
- State space analysis
- Performance analysis
- Behavioural visualisation
- Formal definitions

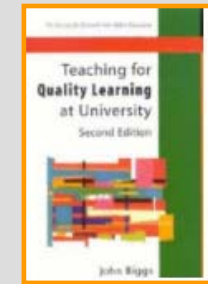
## Part 2: Applications

- Collection of small, medium, and large-scale examples from different domains.



# Intended Learning Outcomes and Constructive Alignment

- Formulation of intended learning outcomes is based on the Structure of the Observed Learning Outcome (SOLO) taxonomy [Biggs'03].



Level 5: Extended abstract

Level 4: Relational

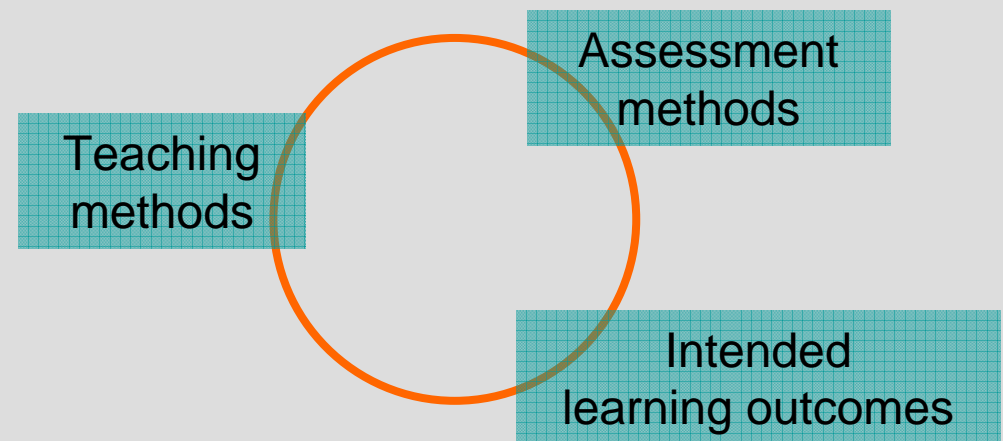
Level 3: Multistructural

Level 2: Unistructural

Level 1: Prestructural

Learning competences

## Constructive alignment



- Introduction coincides with a new Danish assessment scale and the university ECTS certification process.



# Intended Learning Outcomes Q1

- **ILO-1** explain(4) the constructs and concepts in the CPN modelling language.
- **ILO-2** define(2) and explain(4) the syntax and semantics of CPNs.
- **ILO-3** define(2) and explain(4) properties for characterising the behaviour of concurrent systems.
- **ILO-4** explain(4) the basic concepts and techniques underlying state space analysis methods.
- **ILO-5** apply(4) CPNs and CPN Tools for modelling and validation of smaller concurrent systems.
- **ILO-6** judge(4) the applicability of CPNs for modelling and validation of a concrete concurrent system.



# Teaching and Assessment Methods Q1

Session	Topic	Teaching Method	Material
1	Why modelling and validation?	Lecture	Chapter 1 of [15]
2	Basic concepts	Lecture	Chapter 2 of [15]
3	CPN ML programming	Lecture	Chapter 3 of [15]
4	Modelling	Workshop	Small exercises
5	Formal Definition of CPNs	Lecture	Chapter 4 of [15]
6	Modelling	Workshop	Project 1
7	Hierarchical CPNs	Lecture	Chapter 5 of [15]
8	State Space Analysis (1)	Lecture	Chapter 7 of [15]
9	State Space Analysis (2)	Lecture	Chapter 7 of [15]
10	State Space Analysis	Workshop	Project 2
11	Timed CPNs	Lecture	Chapter 9 of [15]
12	Performance analysis	Lecture	Chapter 11 of [15]
13	Industrial applications	Lecture	Selected chapters from part II of [15]
14	Course evaluation	Discussion	

**ILO-1 explain** the constructs and concepts in the modelling language.

**ILO-2 define** and **explain** the syntax and semantics.

**ILO-3 define** and **explain** properties for characterising the behaviour of concurrent systems.

**ILO-4 explain** the basic concepts and techniques underlying state space analysis.

**ILO-5 apply** CPNs and CPN Tools for modelling and validation of smaller concurrent systems.

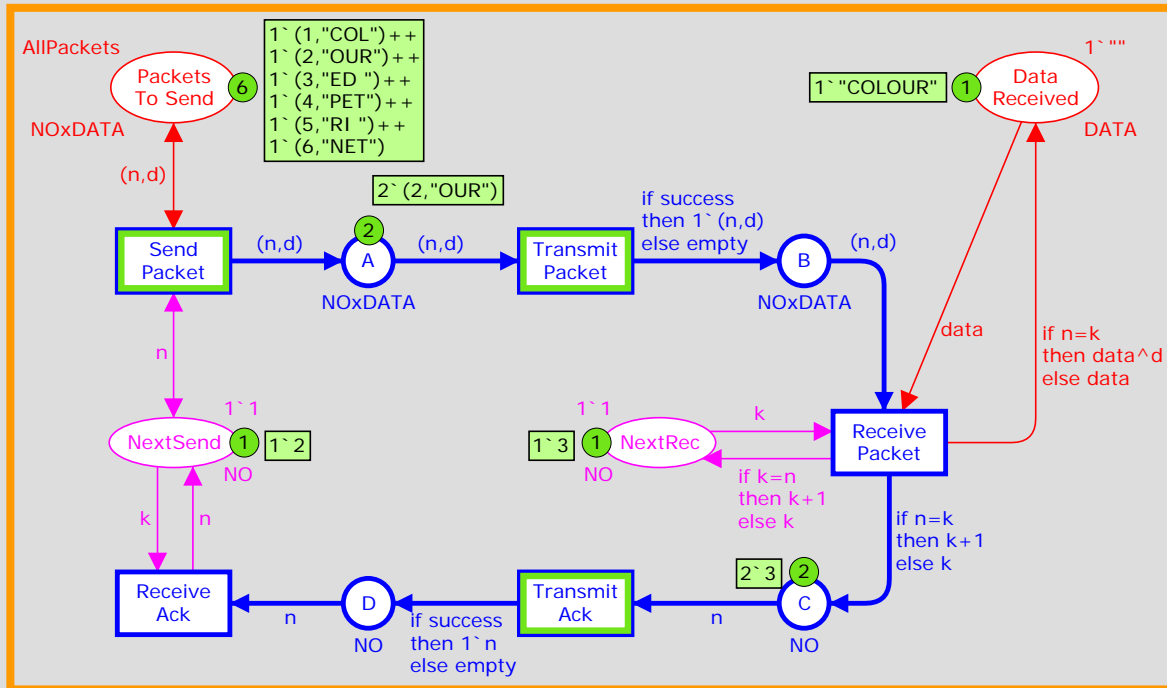
**ILO-6 judge** the practical application for modelling and validation of concurrent systems.

- **Project work conducted in groups of 2-3 persons.**
- **Approval of project work required to enrol for the oral exam.**



# Lectures

- Practically oriented.
- A protocol system is used as a running example:

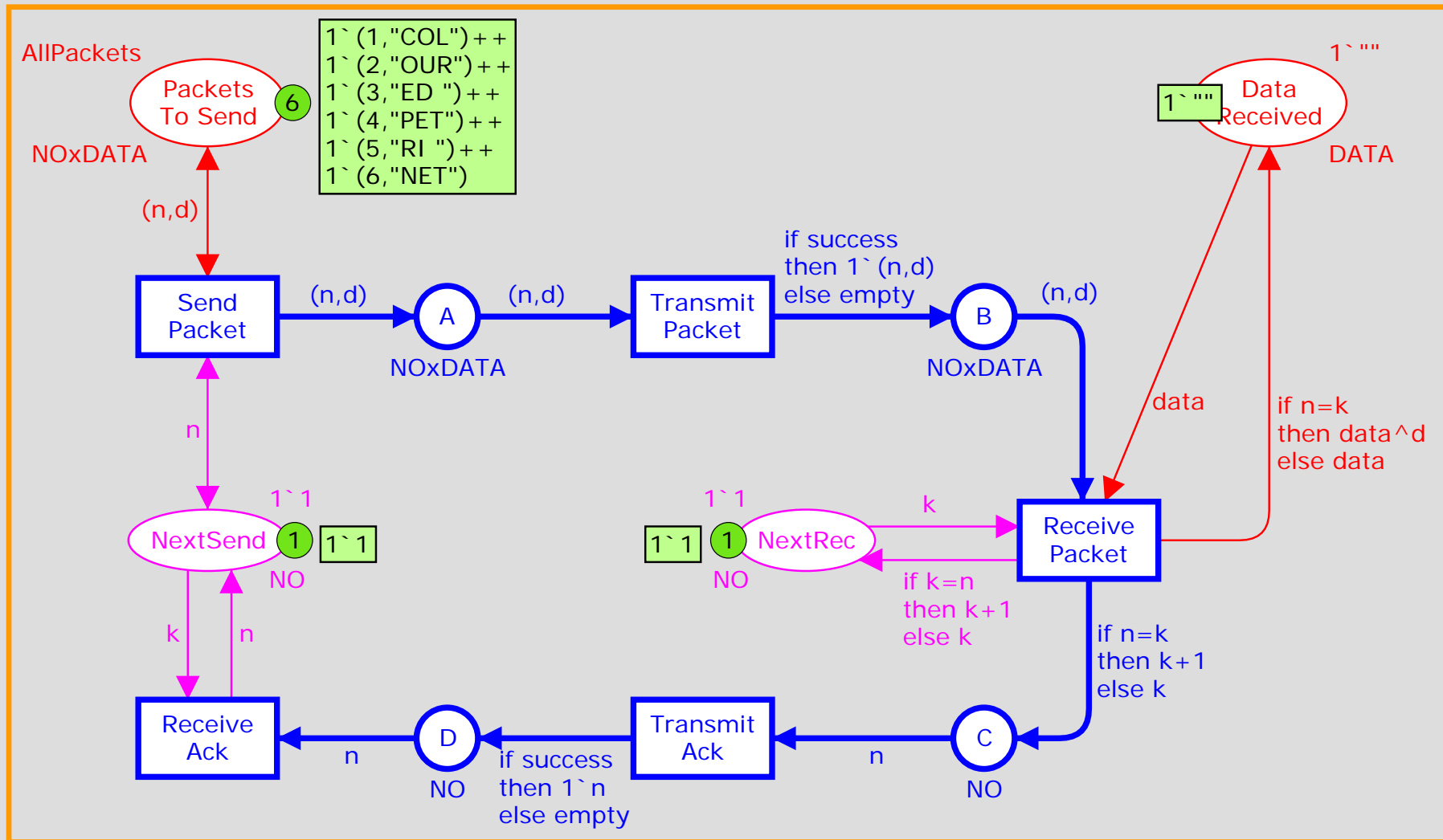


- CPN ML programming
- Hierarchical models
- Timed models
- State space analysis
- Performance analysis
- Behavioural visualisation

- Philosophy is to teach CPNs as a programming language.



# Protocol System



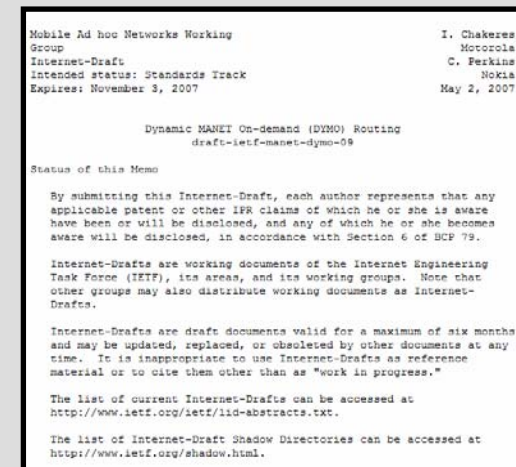
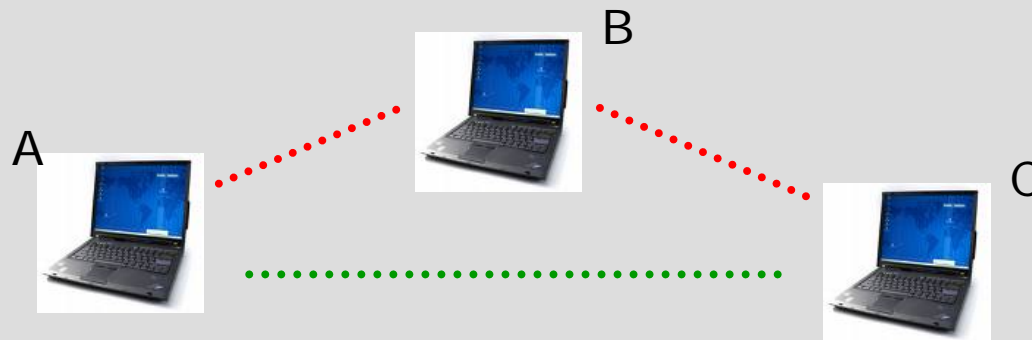
# Second Quarter

- **Intended learning outcomes Q2:**
  - **ILO-7** `construct(3)` and `structure(3)` CPN models of larger concurrent systems.
  - **ILO-8** `apply(4)` analysis methods for CPNs for validation of larger concurrent systems.
  - **ILO-9** `discuss(5)` the application of CPNs for modelling and validation of larger concurrent systems.
- **Teaching methods:**
  - Participants conduct a larger project on modelling and validation and writes a report.
  - No conventional lectures: two progress workshops.
  - Large degree of freedom in defining the projects.
- **Assessment:**
  - Individual 20-minutes oral exam based on the project and the project report.



# Example Project: DYMO Protocol

- On-demand routing protocol for MANETs currently being developed by IETF.
- Infrastructure-less mobile networks with peer-to-peer multi-hop communication:

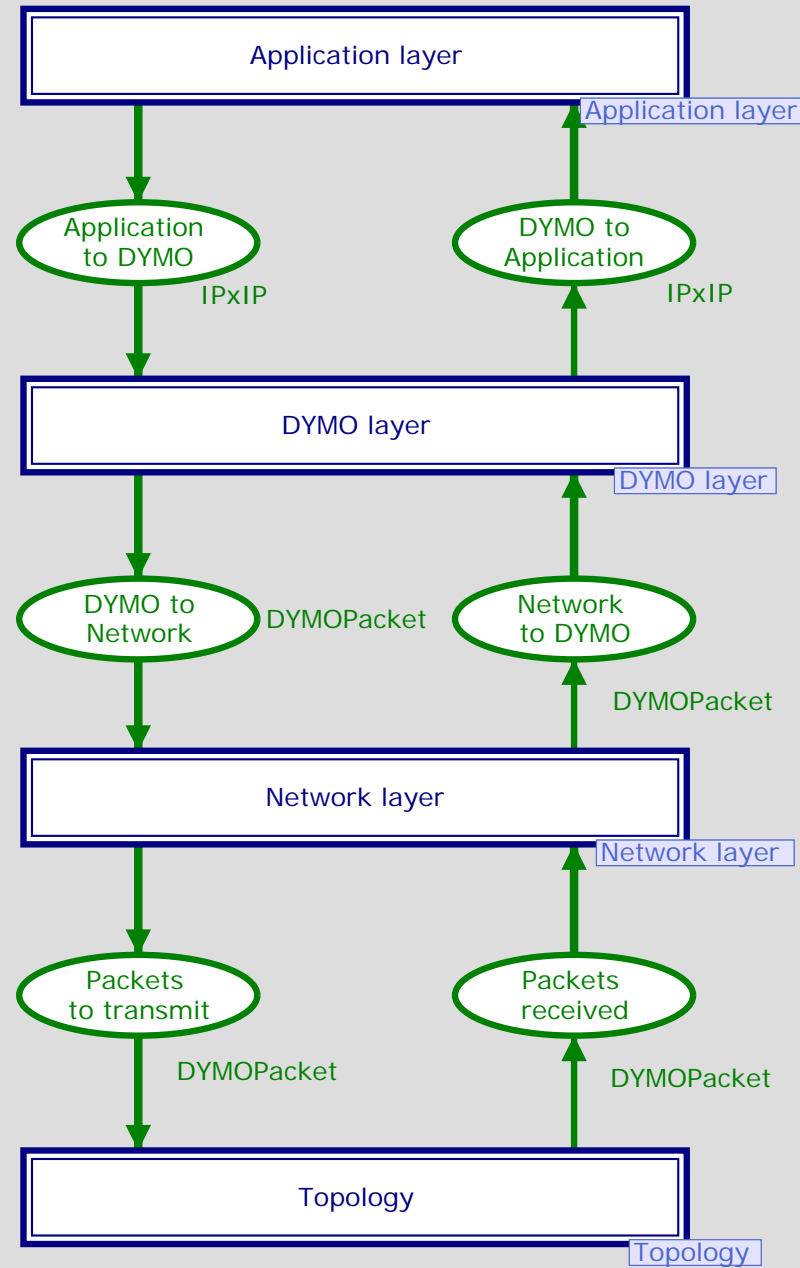


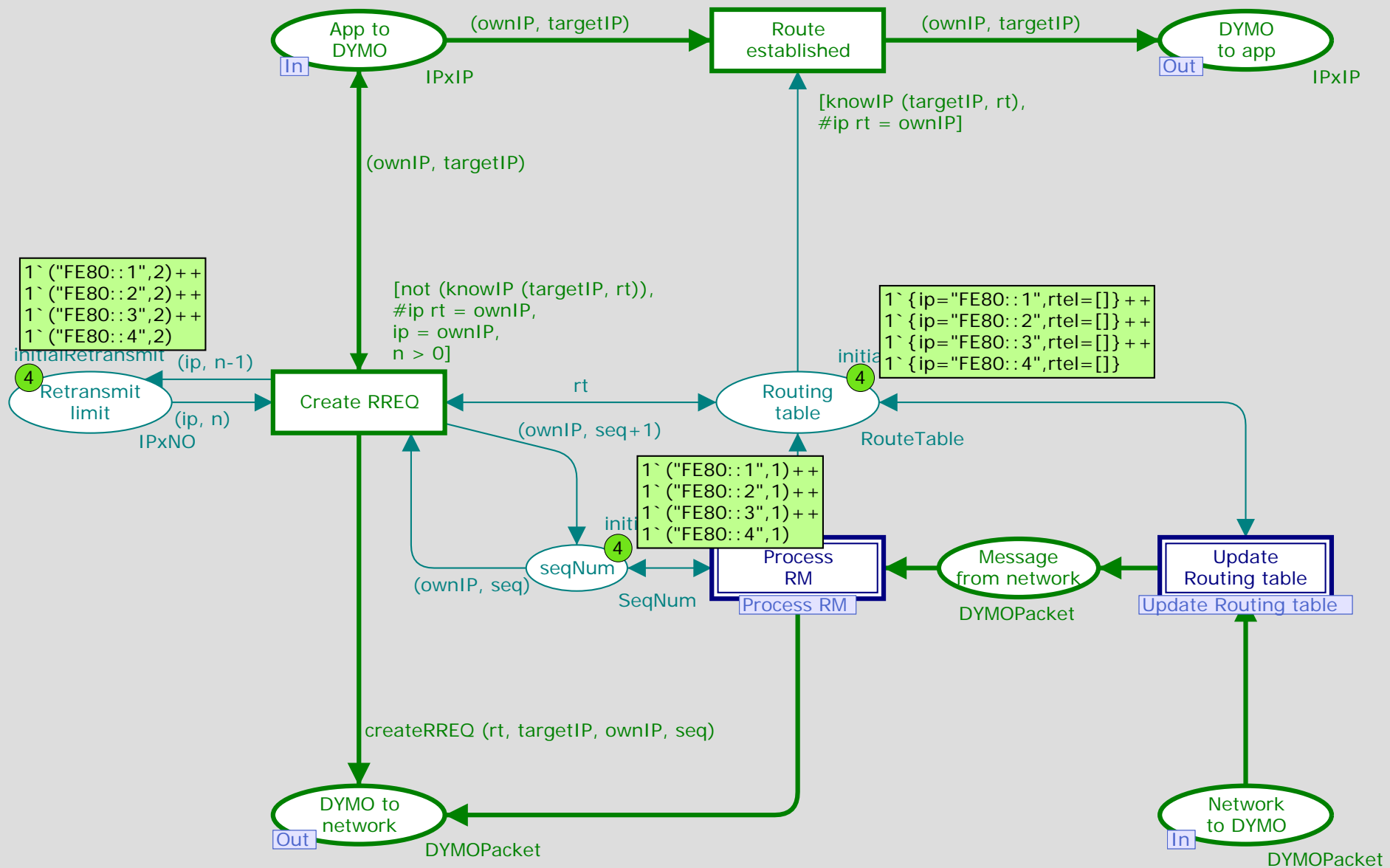
Internet-draft: 33pp.

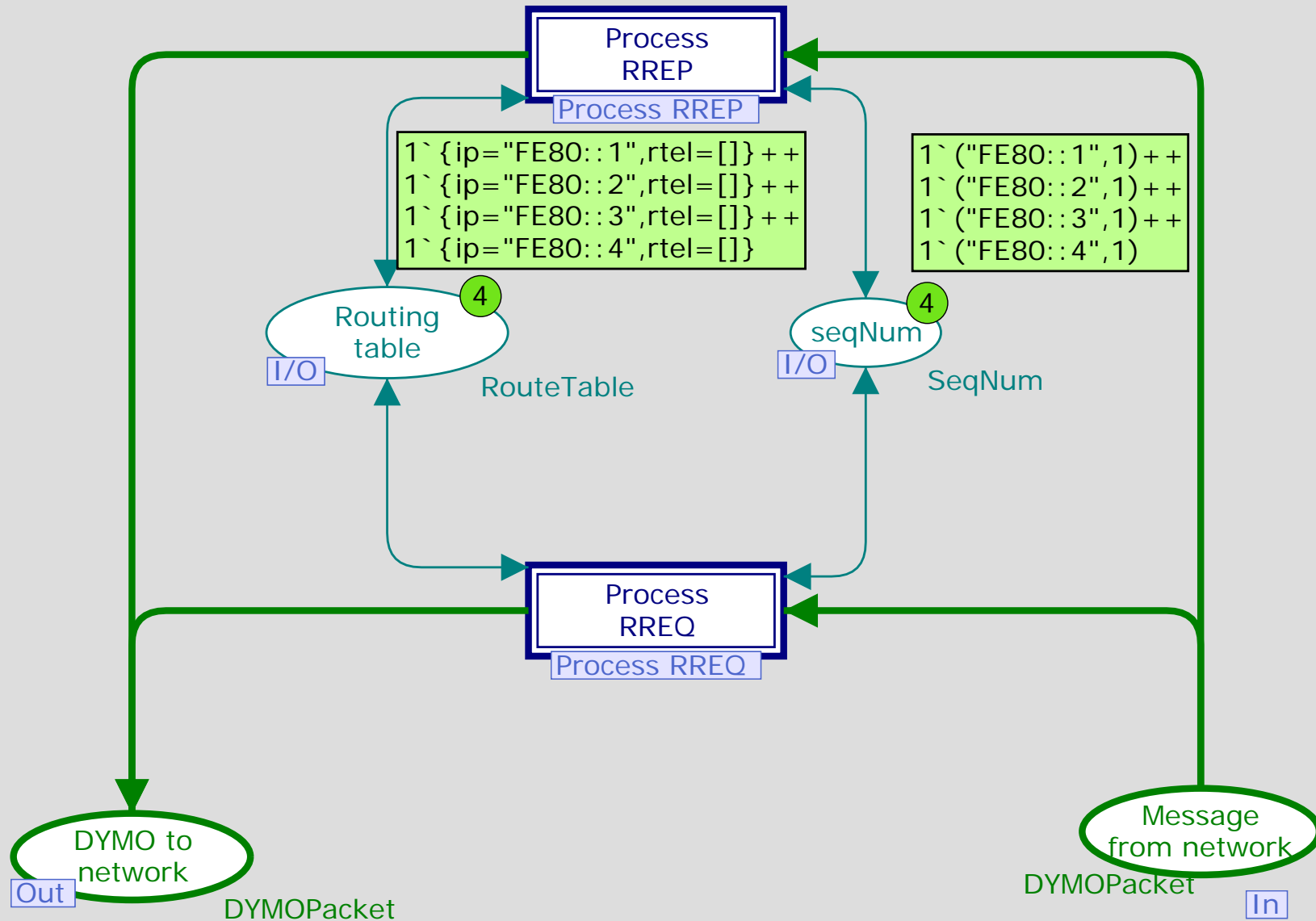
- Large subset of DYMO modelled and selected dynamic properties investigated using state space analysis.

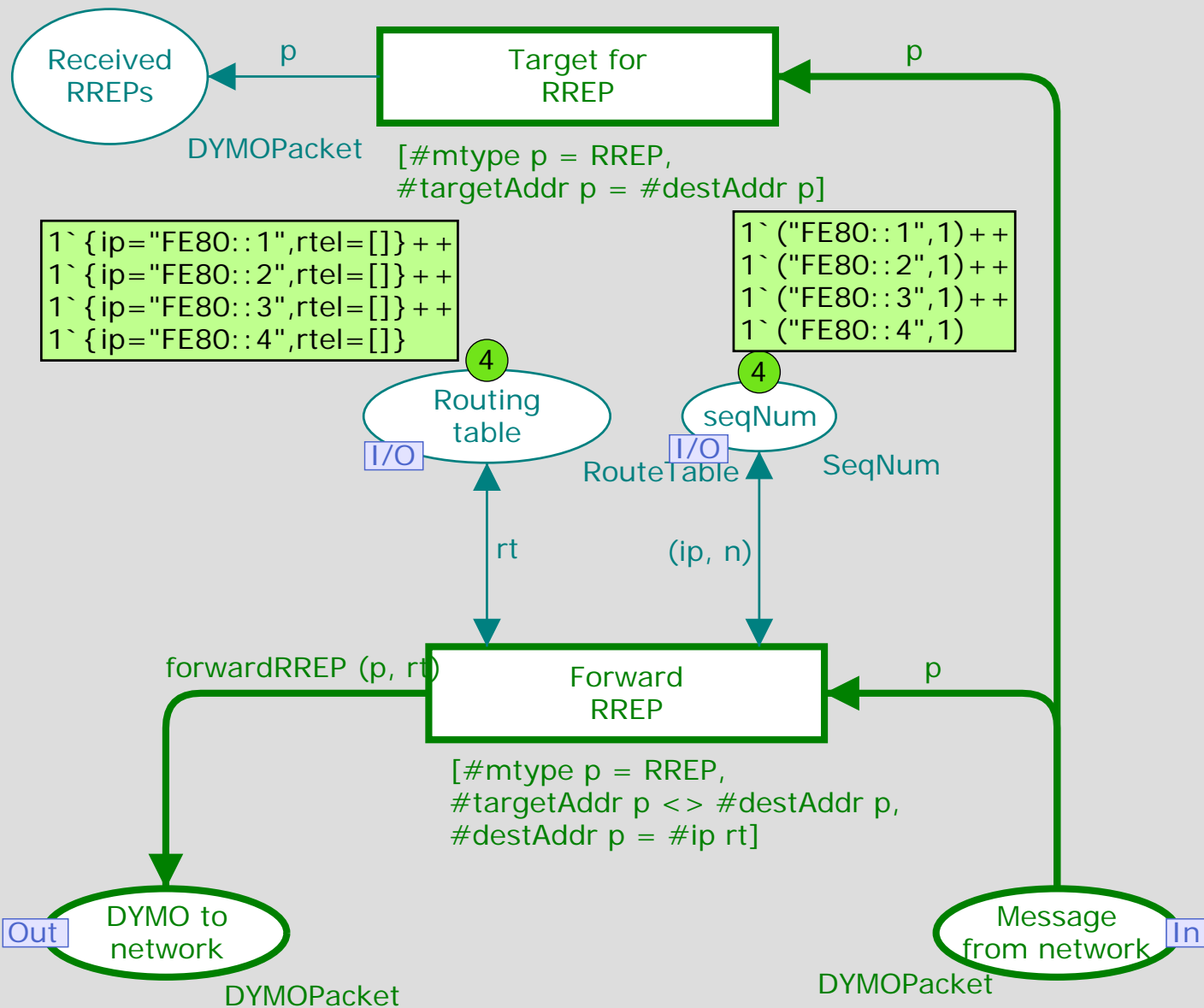


# DYMO-MANET









# Summary and Conclusions

- **Course and textbook developed over the last three years:**
  - More emphasis on CPN ML programming than earlier.
  - CPN Tools to a larger extent integrated in the teaching activities.
- **Coloured Petri Nets introduced directly (not ordinary Petri nets first).**
- **Constructive alignment and the SOLO taxonomy provides a practically applicable framework for improving teaching.**
- **Possible improvements:**
  - First quarter perhaps too focussed on the protocol system – integrate smaller/medium-sized examples from other domains.
  - More workshop/progress sessions in Q2.
  - Second quarter more research focussed: theory, extensions, state space methods, implementation, practical use and applications.



# Participants' Evaluation

\* ~ 12,5 %

	To a very large extent	To a large extent	To some extent	To a lesser extent	Not at all
Course goals achieved	*	*****			
Content match description	**	*****	*		
Course interesting	*	*****	**		
Course difficult			***	****	*
	Very good	good	either way	bad	Very bad
Learning outcome	*	*****		*	
Lectures	*	*****	**		
Workshops/exercises	*	***	****		
Textbook	*	*****	*		
	<4	5-8	9-12	13-16	17-20
Hours used		***	****		
Overall evaluation	*	*****			



# Further Information...

- Course web page:  
[www.daimi.au.dk/~kris/CPN/](http://www.daimi.au.dk/~kris/CPN/)
- CPN Book home page (eventually)  
[www.daimi.au.dk/cpnbook/](http://www.daimi.au.dk/cpnbook/)
- CPN Tools  
[www.daimi.au.dk/CPNtools](http://www.daimi.au.dk/CPNtools)

