Timed Petri Nets with OpenModelica

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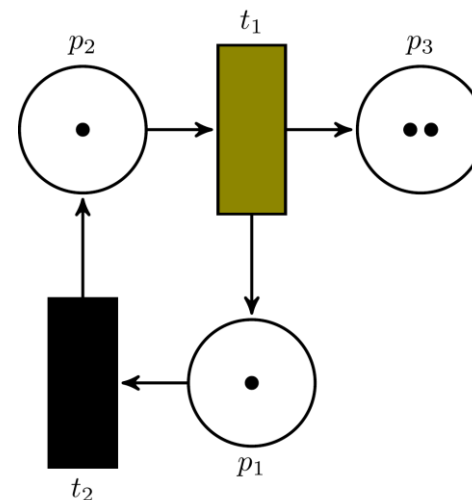
Outline

- Petri nets
    - Basic concepts
    - Modelica library "PNlib"
- Application cases
    - Nursing staff planning in a hospital
    - Carbon fluxes in metabolic systems
- Further developments

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Petri nets

- Basic concepts
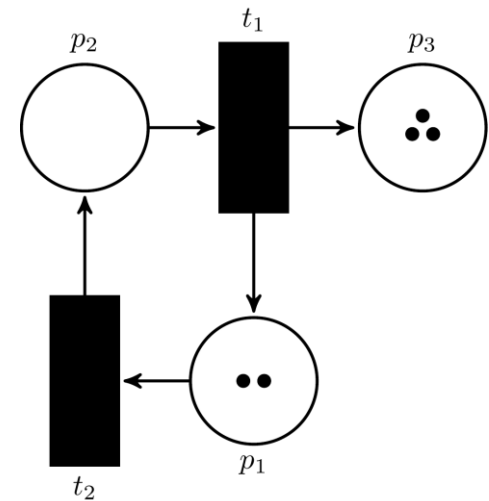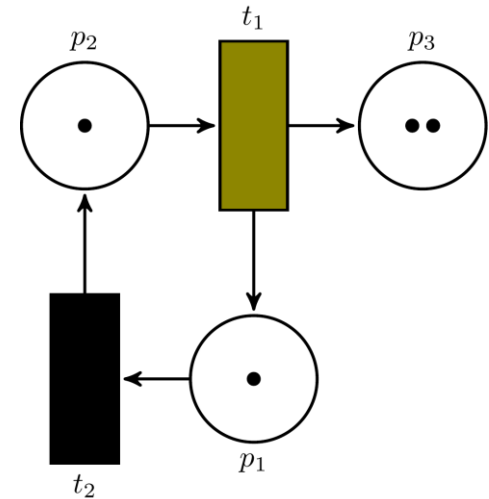- Modelica library "PNlib"

Basic concepts

- Petri nets consist of
  - Places
  - Transitions
  - Edges

Basic concepts

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  - Places
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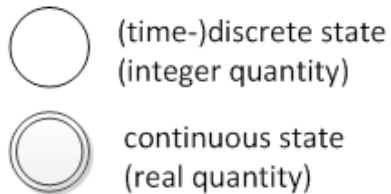- Petri nets describe state (marking) and behaviour (firing) of systems

Basic concepts

- Multitude of extensions, e.g.
  - Timed Petri nets
  - Continuous Petri nets
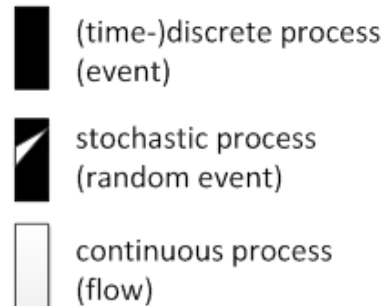 - Coloured Petri nets
  - Fuzzy Petri nets
  - ...

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Modelica library "PNlib"

- xHPN: Extended Hybrid Petri Nets

Places

○ (time-)discrete state (integer quantity)

◎ continuous state (real quantity)

Transitions

▮ (time-)discrete process (event)

▨ stochastic process (random event)

▯ continuous process (flow)

Arcs

——▶ „normal" arc

——○ inhibitor arc

— — —▶ test arc

——● read arc
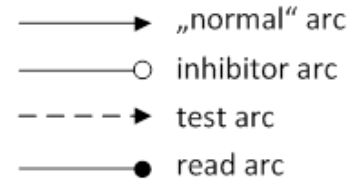
- Mathematical formalism
  – pub.uni-bielefeld.de/publication/2562185

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Modelica library "PNlib"

- Freely available
  - github.com/modelica-3rdparty/PNlib

- Version 2.0 released in December '16

- Fully supported by OpenModelica

Modelica library "PNlib"

- OpenModelica coverage trend for the last 2 years
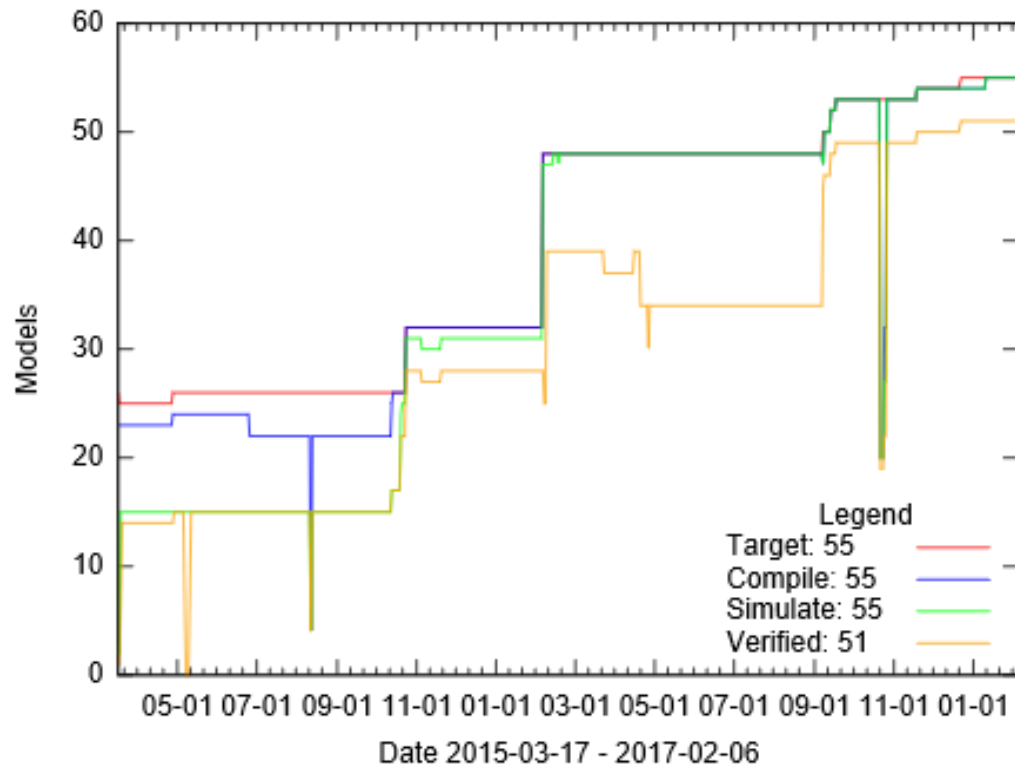
Application cases

- Nursing staff planning in a hospital
- Carbon fluxes within metabolic systems

Nursing staff planning in a hospital

- Problem behind the scenes:
  - Expert deficit
  - Early career exit
  - Early retirement

- Objective: Increase the attractiveness of the working time concept
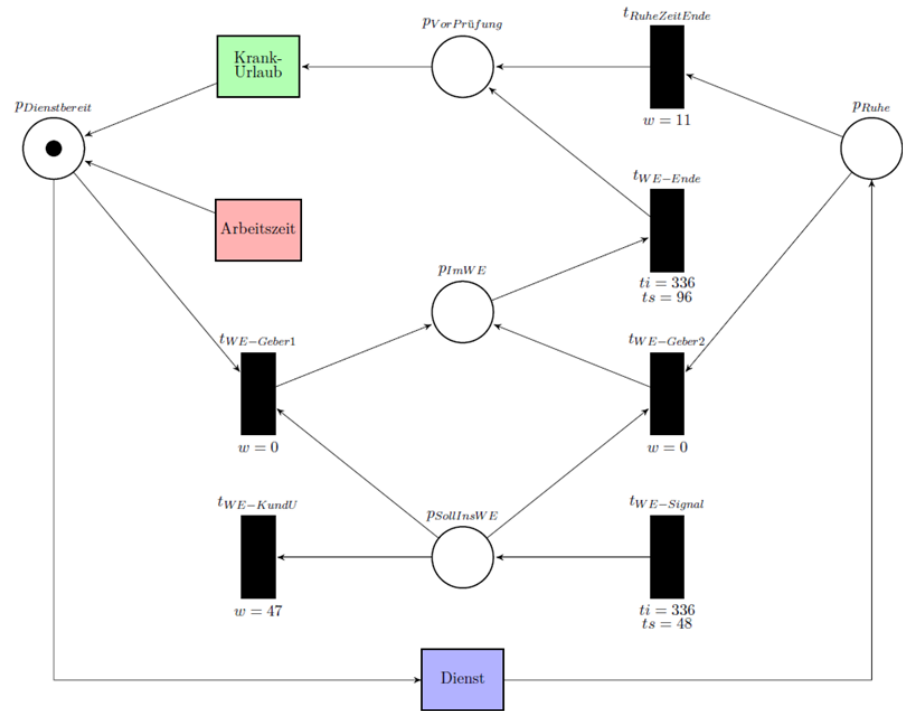
Nursing staff planning in a hospital

- Objective: Increase the attractiveness of the working time concept

  – Employee-oriented human resources planning

  – Employee-oriented working time organization

- Case study by a geriatric ward *(Lask et al. 2016)*

  – Current situation: 12-day week using 3 shifts

  – Comparison of different shift systems using 10-day week

Nursing staff planning in a hospital

- Agent-based simulation of the ward
  - Nursing staff with different qualifications
  - Shift system and weekend arrangement
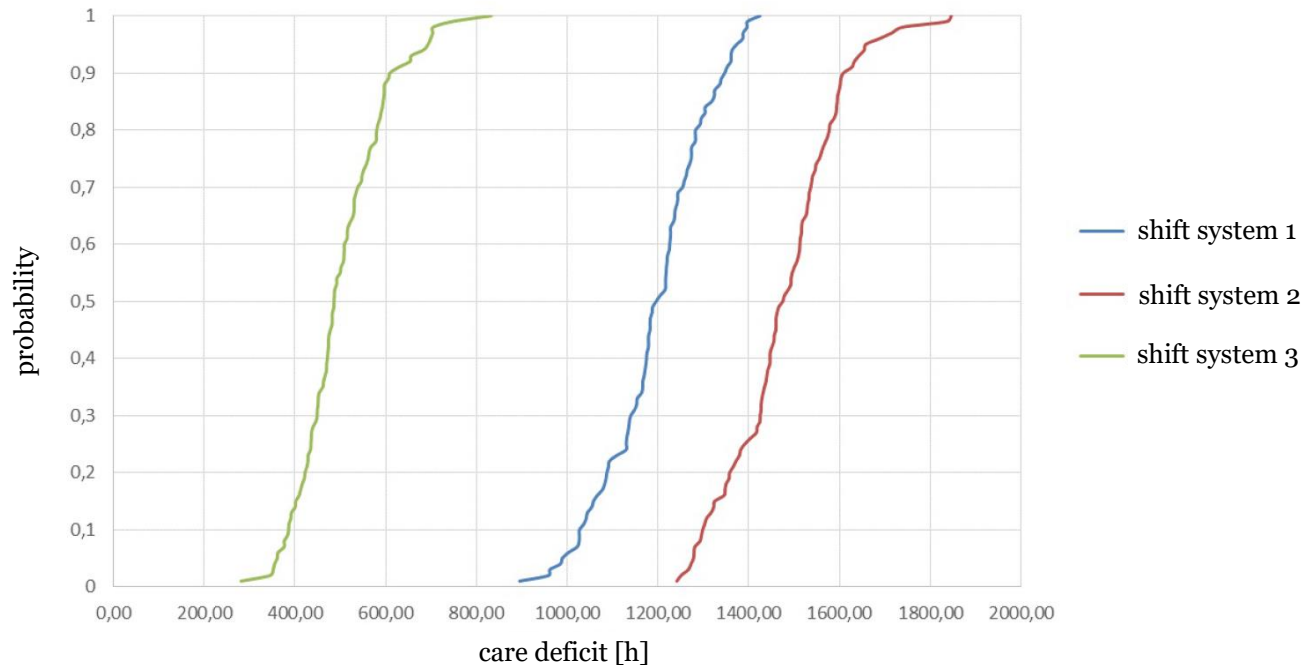 - Illness-related failures
  - Weekly working hours
  - ...

Nursing staff planning in a hospital

- Large scale Petri net

- Trained with real data
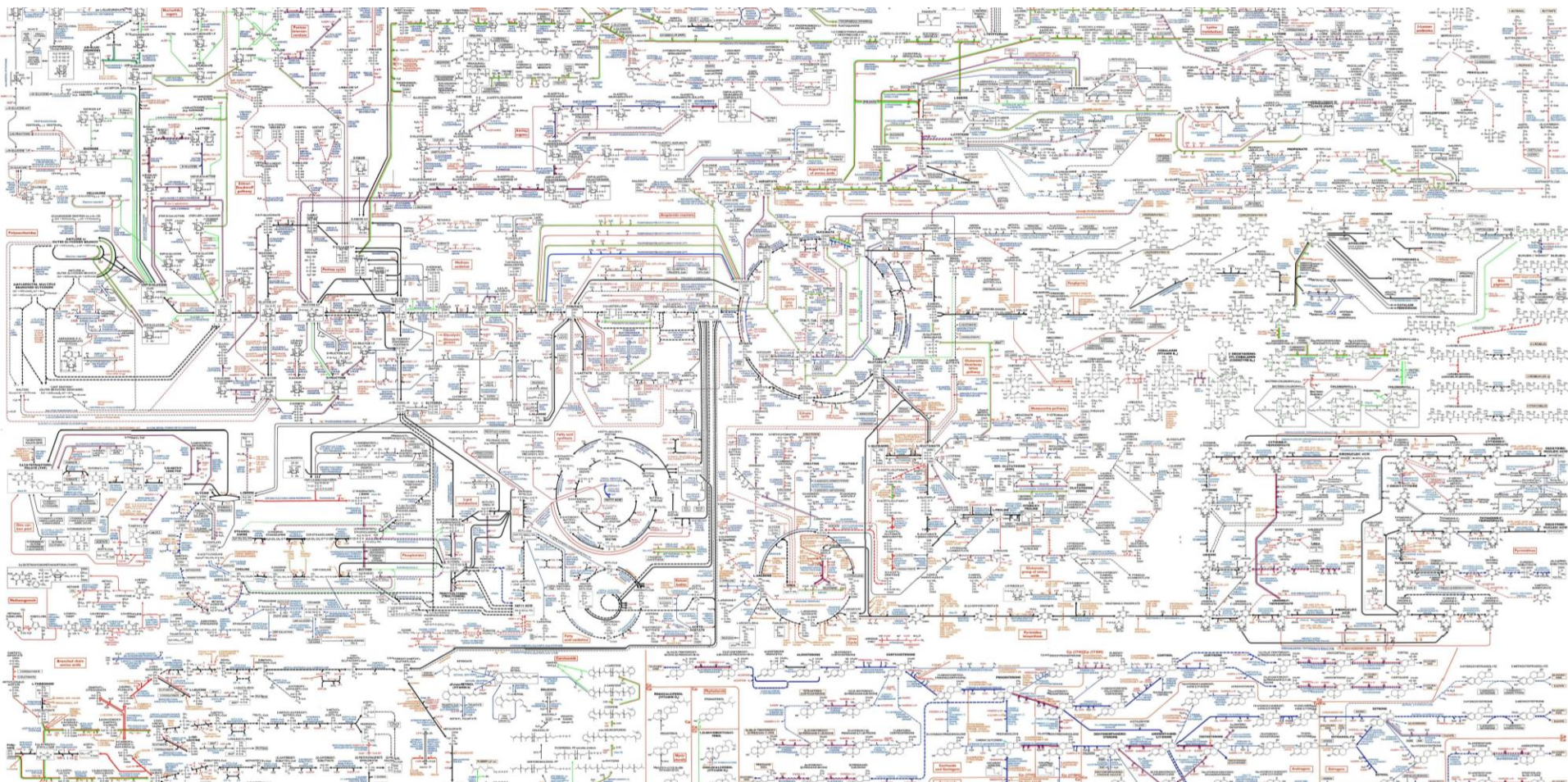
- Stochastic simulation

Nursing staff planning in a hospital

- Result: Stochastic feasibility statement about expected care deficit based on different shift systems

Carbon fluxes within metabolic systems
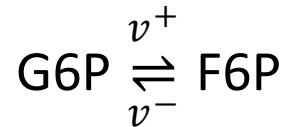
Carbon fluxes within metabolic systems

- Metabolic pathways describe connected enzyme reactions and their intermediate products

- Metabolic pathways are usually highly connected and contain a lot of competitive paths

- Most relevant metabolites contain carbon

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Carbon fluxes within metabolic systems

- Objective: Investigation of the influence of certain metabolites, e.g. glucose

- Modelling using Petri net formalism
  - Places represent metabolites and other intermediate products
  - Transitions represent (enzyme) reactions

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Carbon fluxes within metabolic systems

- Simple example: Glucose-6-phosphate isomerase

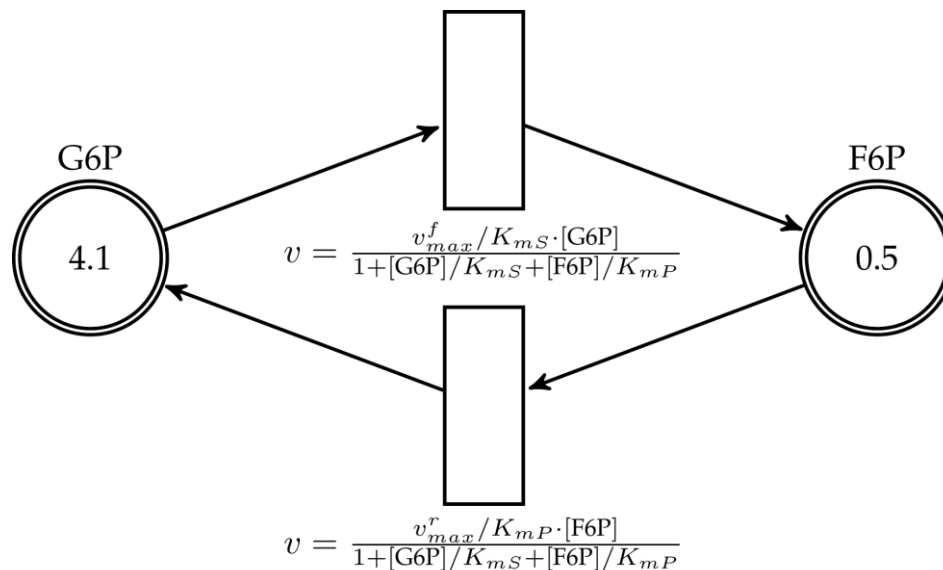$$\text{G6P} \underset{v^-}{\overset{v^+}{\rightleftharpoons}} \text{F6P}$$

- ODE system based on Michaelis-Menten kinetics

$$\frac{d[\text{G6P}]}{dt} = v^- - v^+ = \frac{v_{max}^r/K_{mP} \cdot [\text{G6P}] - v_{max}^f/K_{mS} \cdot [\text{F6P}]}{1 + [G6P]/K_{mS} + [F6P]/K_{mP}}$$

$$\frac{d[\text{F6P}]}{dt} = v^+ - v^- = \frac{v_{max}^f/K_{mS} \cdot [\text{F6P}] - v_{max}^r/K_{mP} \cdot [\text{G6P}]}{1 + [G6P]/K_{mS} + [F6P]/K_{mP}}$$
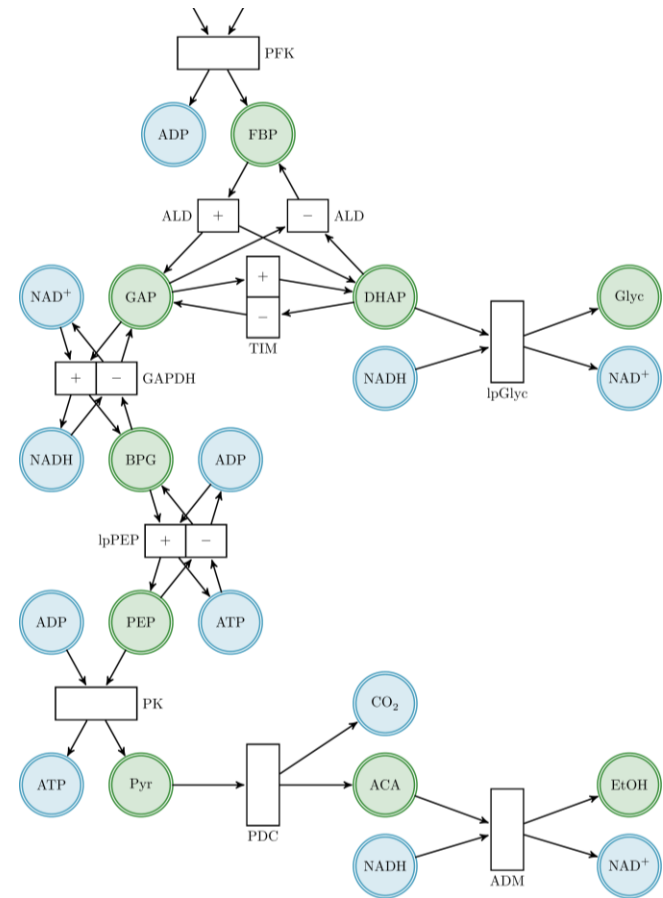
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Carbon fluxes within metabolic systems

- Continuous Petri nets can be used as intuitive representation of such ODE systems

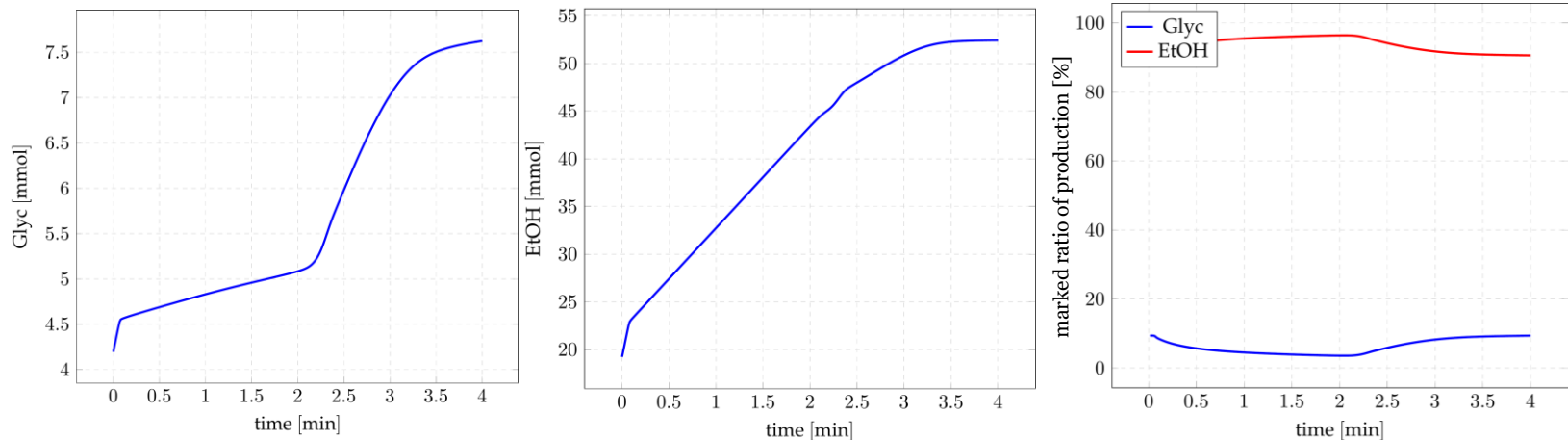# Carbon fluxes within metabolic systems

- Glucose (food) is consumed
- Glyc and EtOH are produced

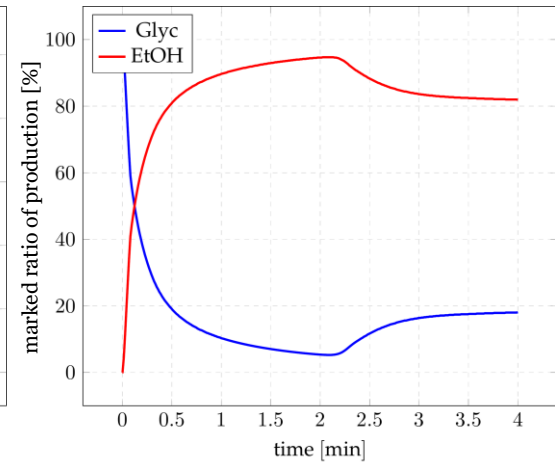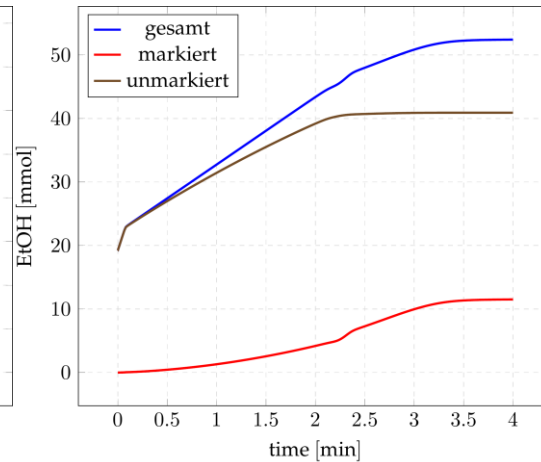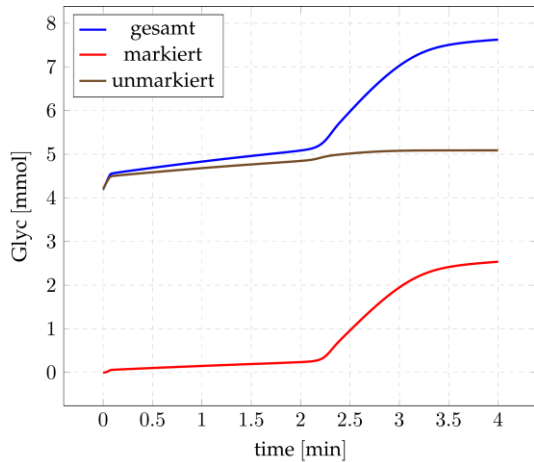- Objective: Distribution of products based on feeding

Carbon fluxes within metabolic systems

- Uncoloured simulation of Glyc and EtOH production

Carbon fluxes within metabolic systems

- Decomposition of Glyc and EtOH production based on (un)labelled carbon

Further developments

New graphical interface

- Graphical Petri net editor
- Fast, slim, and extendible
- Intuitive support of arc weights
- Build-in connection to OpenModelica
- OpenModelica feedback for modelling purpose
- Online simulation visualization

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Thanks for your attention.

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