Modeling Techniques for Business Process Performance Analysis

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Agenda

Business Process Management

Techniques, languages and tools to support process life cycle

- Design, Execution, Monitoring, **Analysis**

Why it is important to analyze business processes?

- They are everywhere (e-commerce, e-government, production)
- Thousands of people depend on their reliability

Qualitative Analysis $\times$ Quantitative Analysis

- Verification (syntactical correction)
- Validation (semantical correction)
- **Performance analysis**

Performance Analysis of Business Processes I

To improve efficiency in organizations we need

- To understand how the operational processes work
- To optimize their functioning

Performance analysis help us

- To identify process inefficiencies (bottlenecks, etc.)
- To make a better provisioning for business processes

Performance Analysis of Business Processes II

Common performance indices

- Responsiveness – service and waiting times
- Productivity – throughput
- Utilization – utilization rate of resources
- Quality of service, reliability

Resource management

- Business tasks depend on resources
- Resources are finite
- Resources must be shared between different process instances

Computational System Performance Analysis

Possible approaches for performance evaluation

- Measuring
- Simulation
- **Analytical modeling**

Characteristics of analytical modeling

- Predictive
- High precision (specially for rare event analysis)
- Provide good insight into the effects of model parameters and their interactions

Business Process Modeling

Domain-specific languages

- *Business Process Model and Notation* (BPMN), *Event-driven Process Chains* (EPC), *Unified Modeling Language* (UML)
- Do not have formal semantics
- Focus on control-flow perspective
- Hard to model resources and quantify modeled behaviors

Stochastic models

- Association of time with tasks
- Association of probabilities with alternative flows
- Characterization of resource usage

From Non-Formal Business Process Models to Stochastic Models

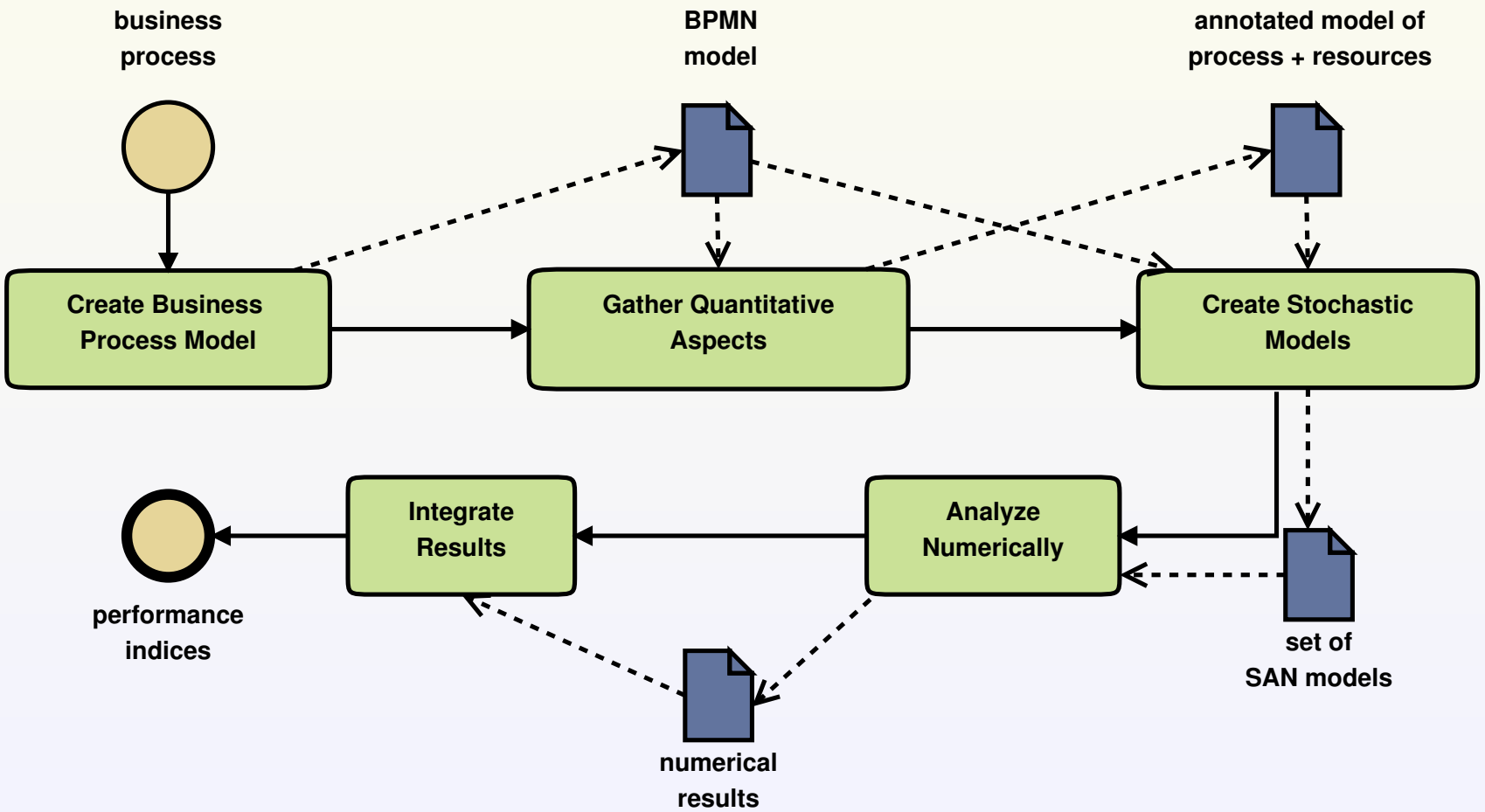
This conversion involves

1. Representation of the flow of tasks
2. Inclusion of quantitative information

Proposed approach

- BPMN $\Rightarrow$ SAN (*Stochastic Automata Networks*)
- Stochastic parameters are extracted from resource management info

Performance Evaluation of Business Processes via Analytical Modeling



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Contributions of this Work

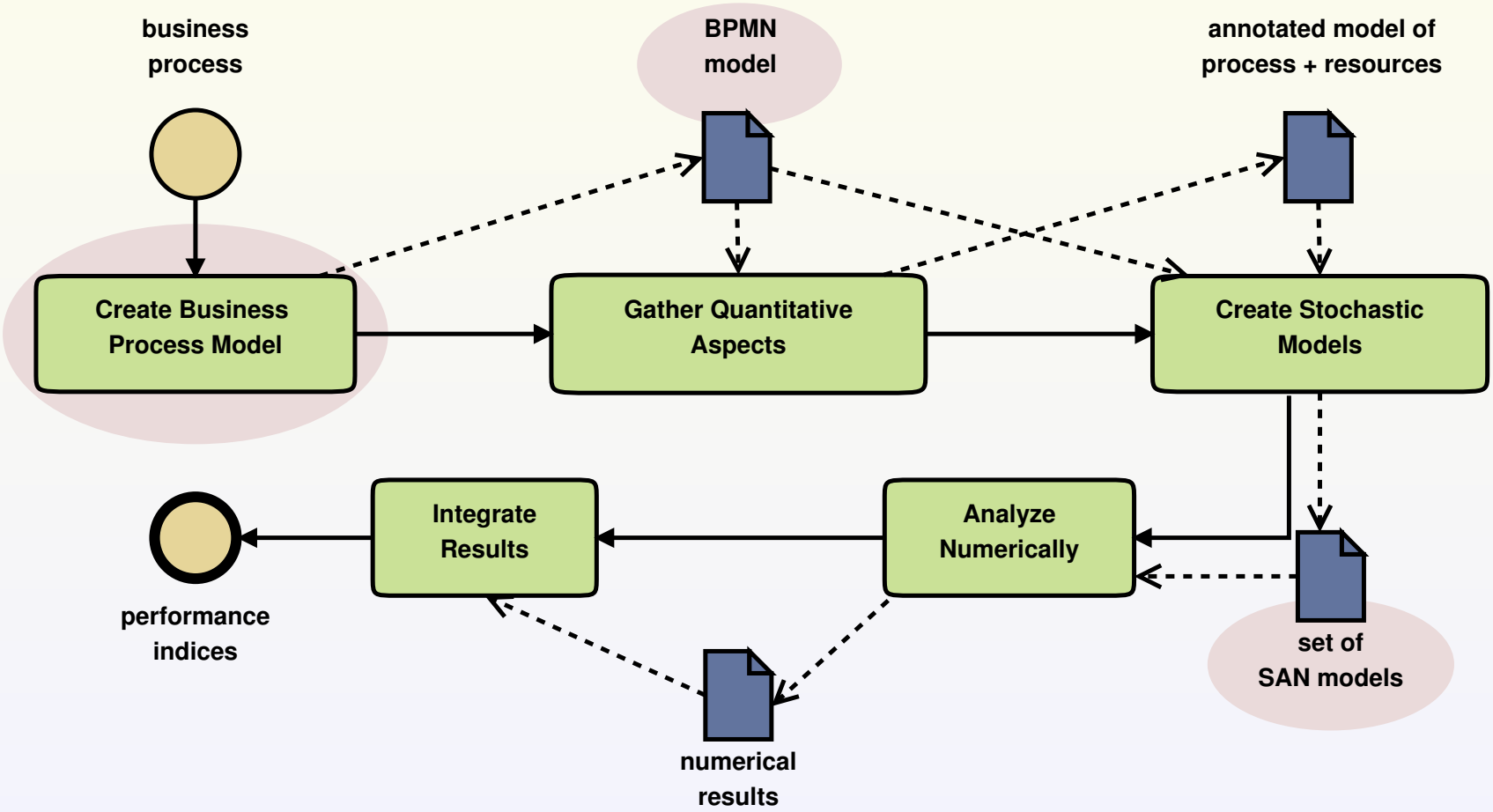
Detailed study of modeling and performance analysis of business processes

- Identification of deficiencies of domain-specific models
- Comparison of stochastic modeling techniques

Automated framework for performance evaluation of resource-aware business process models

- Introduction of resource management in business process models
- Automated conversion from BPMN models to SAN models
- Extraction of performance indices from SAN models

Part I: Modeling Techniques Used in this Work



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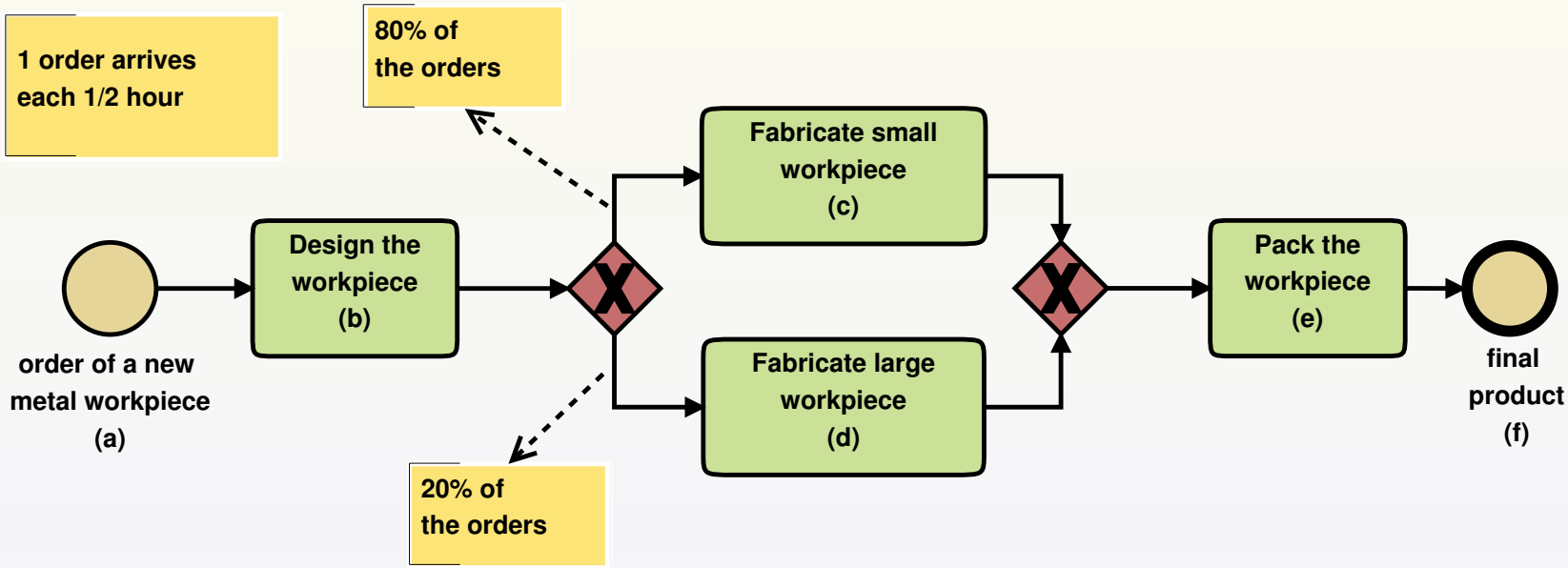
Business Process Model and Notation (BPMN)

- Standard notation (maintained by OMG)
- Best practices of BP modeling
- Processes describe flows of tasks
- Large number of constructors

Example of Process Diagram

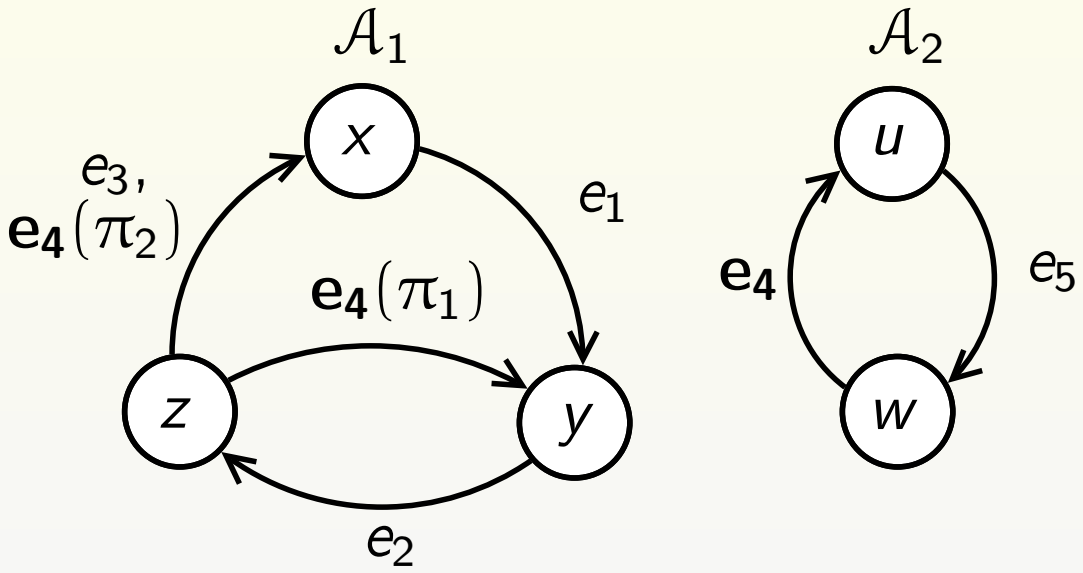
Production process of a small machine shop



Stochastic Automata Networks (SAN)

- Created by Plateau, in 1985
- Technique used to model systems with large state spaces
- Systems are seen as collection of components with infrequent interactions
- A system is described in terms of automata (**states** + **transitions**)
- Changes of state are caused by **events**
- Events can be **local** or **synchronizing**
- Each event has an associated **rate** (a non-negative real number), that can be **constant** or given by a **function**
- Internal representation: Generalized Tensor Algebra

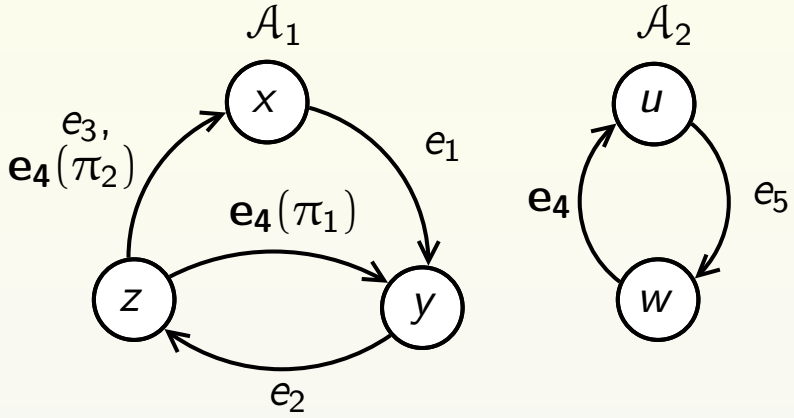
Example of SAN Model



Event	Rate
e_1	τ_1
e_2	τ_2
e_3	τ_3
$\mathbf{e_4}$	τ_4
e_5	f

$$f = \begin{cases} \lambda_1, & \text{if } \mathcal{A}_1 \text{ is in state } x \\ 0, & \text{if } \mathcal{A}_1 \text{ is in state } y \\ \lambda_2, & \text{if } \mathcal{A}_1 \text{ is in state } z \end{cases}$$

Underlying Continuous Time Markov Chain



Event	Rate
e_1	τ_1
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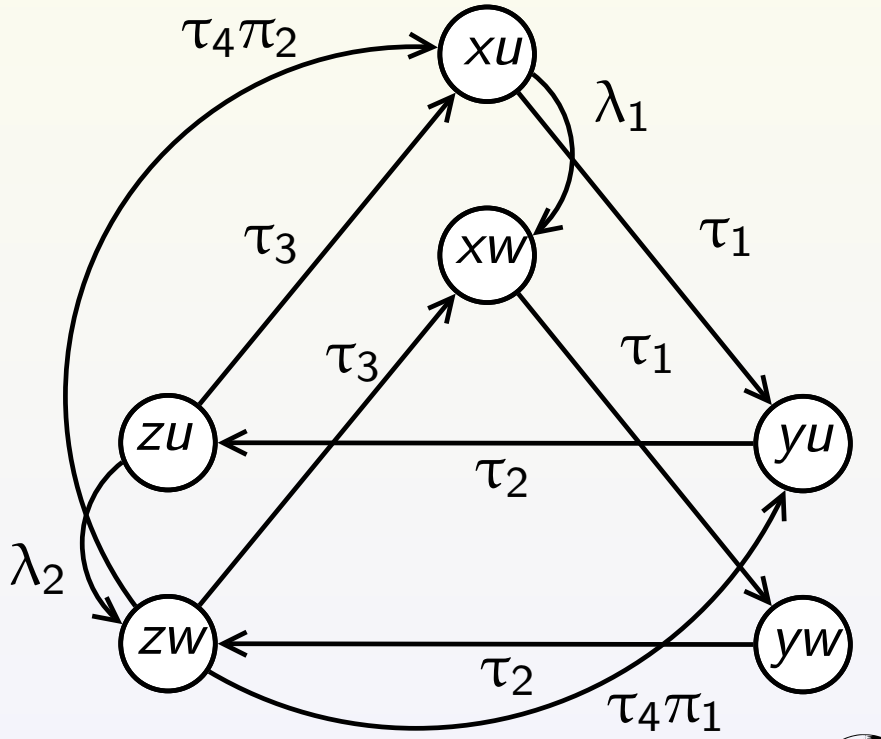
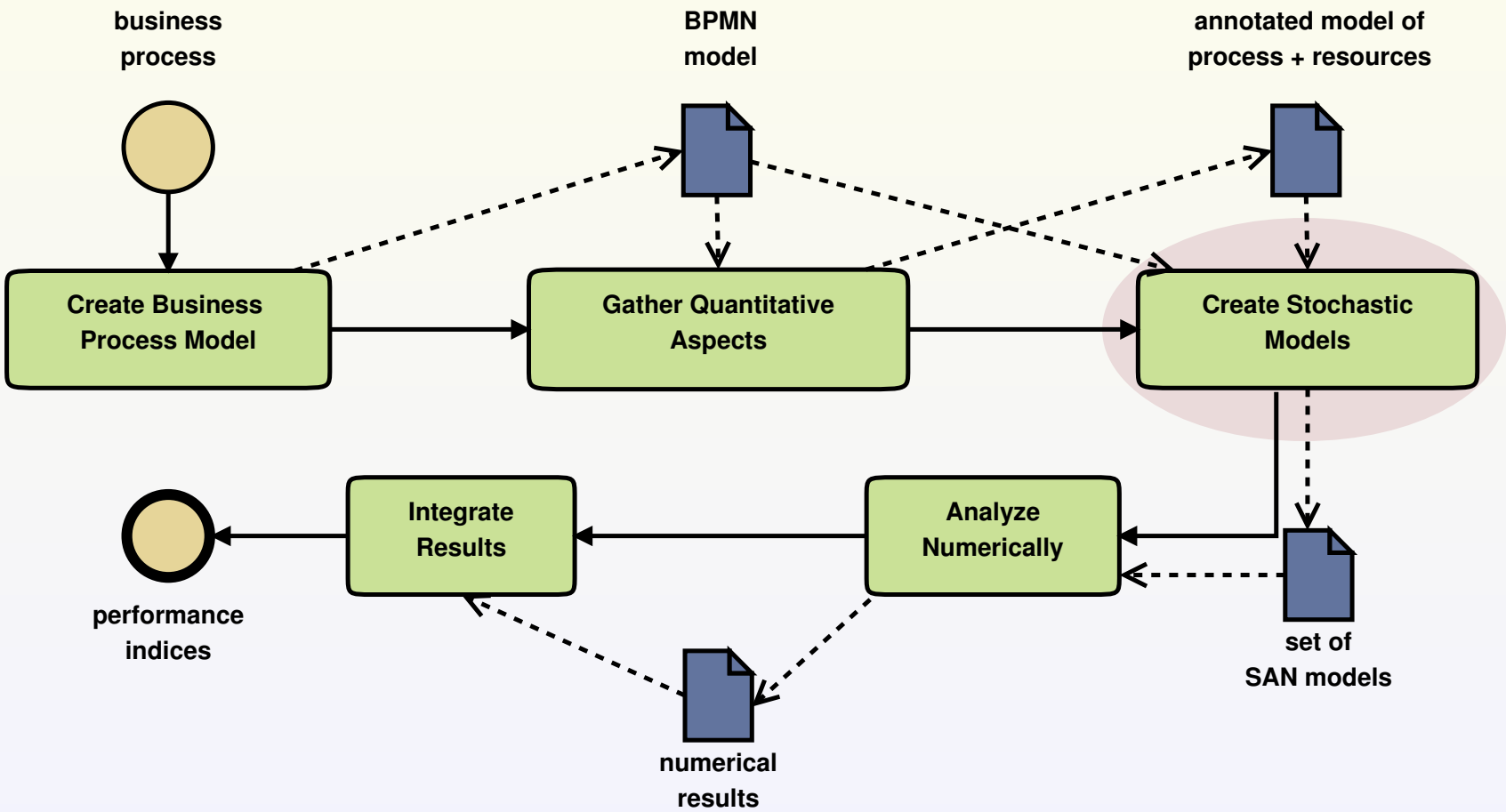


Part II: Conversion of BPMN Models to SAN

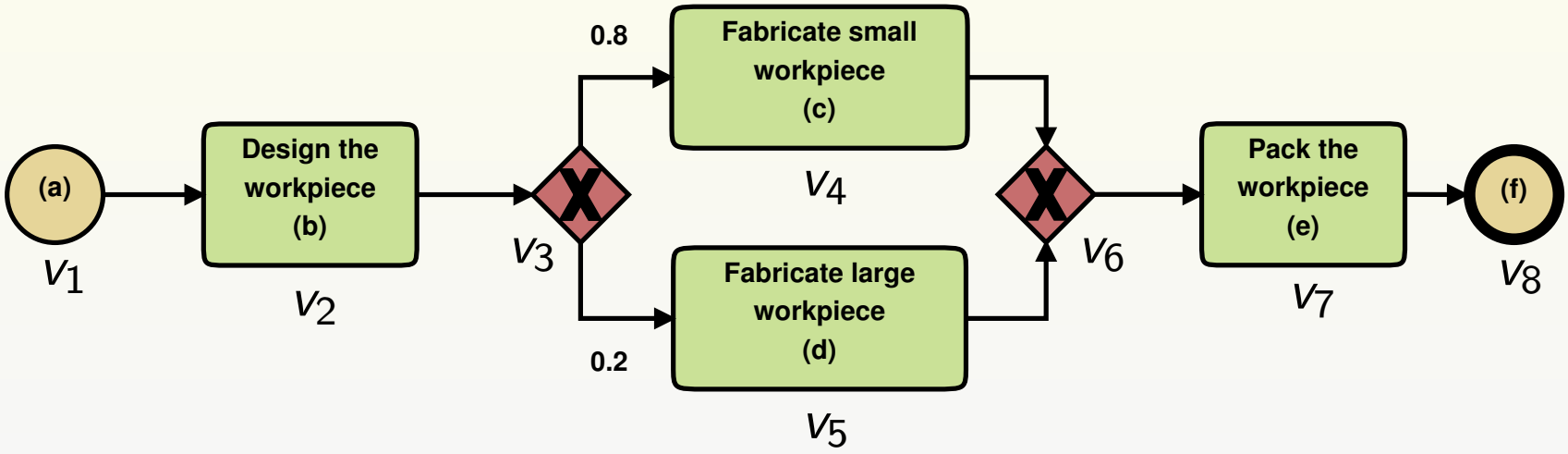


BPMN Process Graph (PG)

$PG = (V, E, L, \ell, \mathrm{p})$ and $V = S \cup A \cup G \cup F$

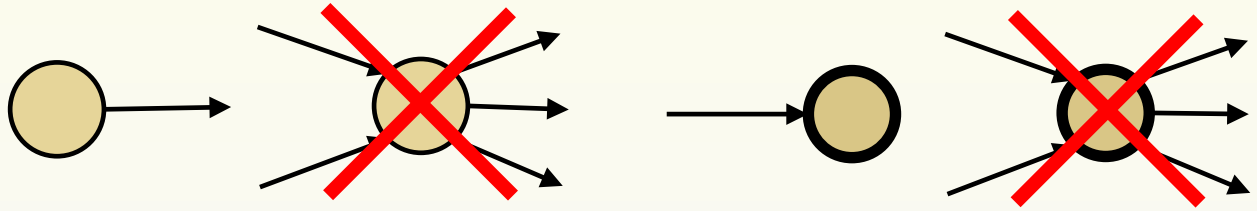
- S – set of start events
- A – set of atomic tasks
- G – set of gateways
- F – set of end events
- $E \subseteq (V \times V)$ – set of directed edges
- L – set of vertex labels
- $\ell : V \longrightarrow L$ – maps labels to vertices
- $\mathrm{p} : E' \longrightarrow [0, 1]$, where $E' \subseteq E$ – maps probabilities to edges

Production Process of a Small Machine Shop

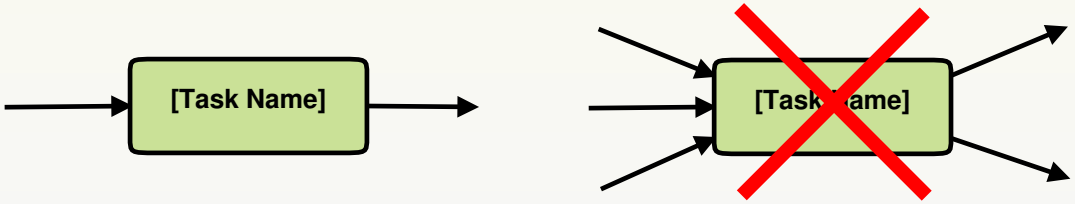


Well-Formed BPMN Process Graph

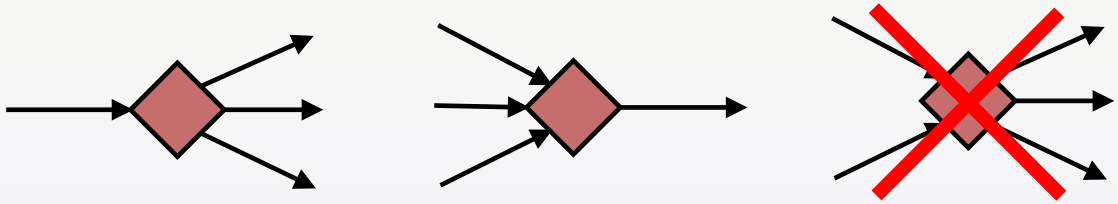
- Vertices accessible from start event / access end event
- Events



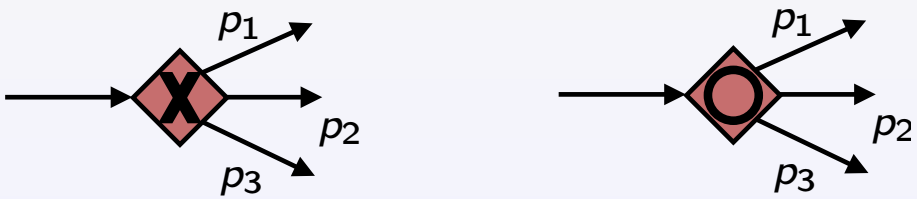
- Tasks



- Gateways



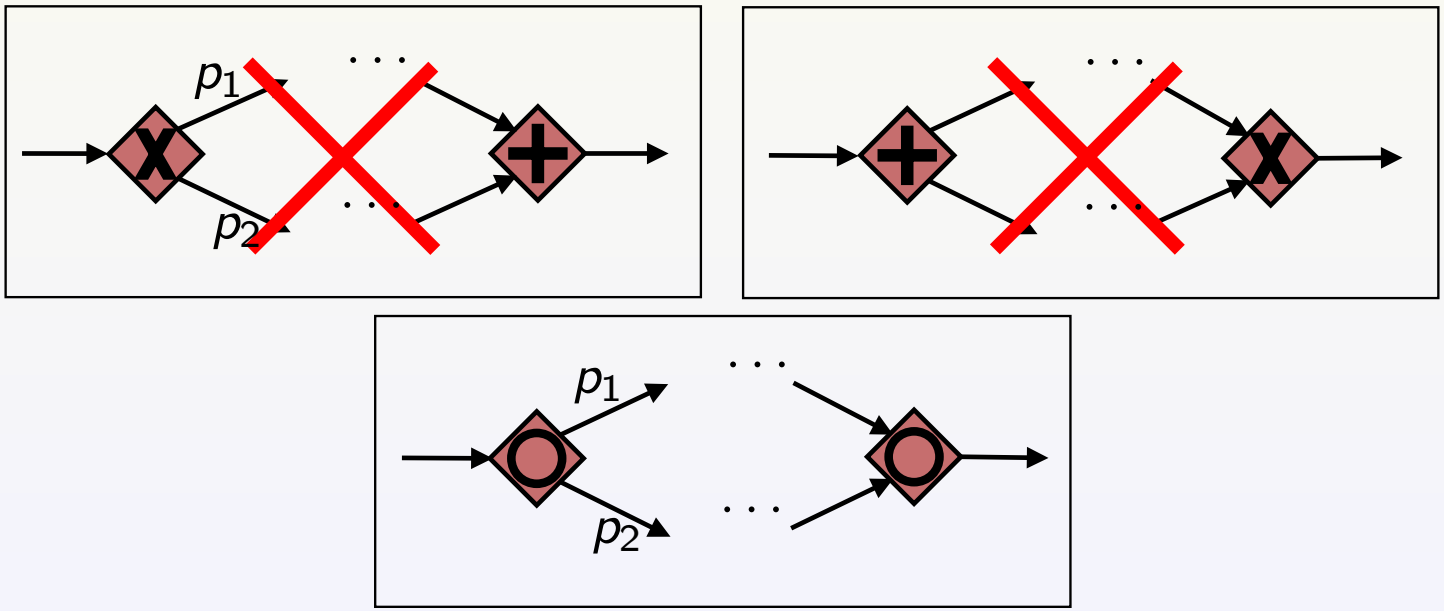
- Probabilities



$$p_1 + p_2 + p_3 = 1$$

Well-Defined BPMN Model

- An exclusive gateway does not join parallel sequence flows
- A parallel gateway does not join exclusive sequence flows
- An inclusive gateway only joins sequence flows originated by another inclusive gateway (one-to-one correspondence)



SAN Model ($\mathcal{S}$) and SAN Automaton ($\mathcal{A}$)

$\mathcal{S} = \{\mathcal{A}_1, \mathcal{A}_2, \ldots, \mathcal{A}_N\}$
$\mathcal{A} = (Q, E, T, L, \ell, \mathrm{p})$, where:

- Q – set of states
- E – set of events
- $T \subseteq (Q \times Q \times E)$ – set of state transitions labeled by events
- L – set of state labels
- $\ell : Q \longrightarrow L$ – associates labels to states
- $\mathrm{p} : T' \longrightarrow [0, 1]$, where $T' \subseteq T$ – associates probabilities to transitions

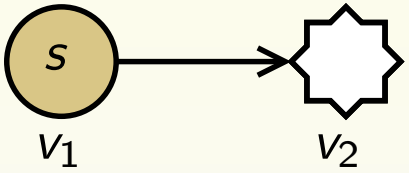
Conversion Algorithm

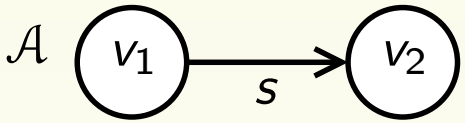
Main Steps

1. Conversion of vertices of the BPMN process graph into elementary SAN models
2. Operations of concatenation to join automata that models a same sequence flow
3. Operations of reduction, to eliminate redundant or unnecessary states

From BPMN Objects to SAN Elementary Models

Start Event

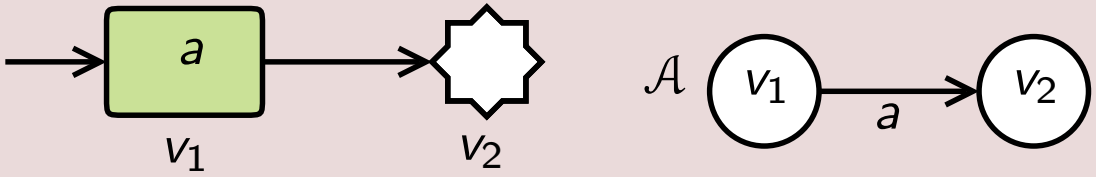




From BPMN Objects to SAN Elementary Models

Start Event

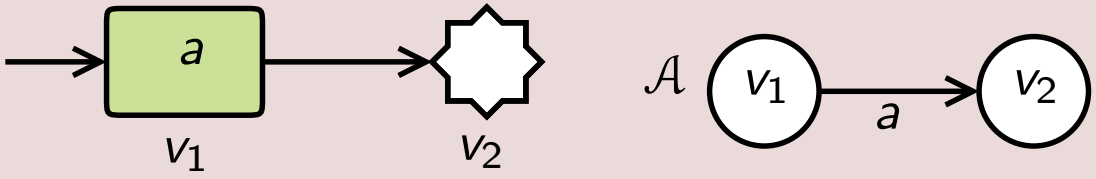
Atomic Task



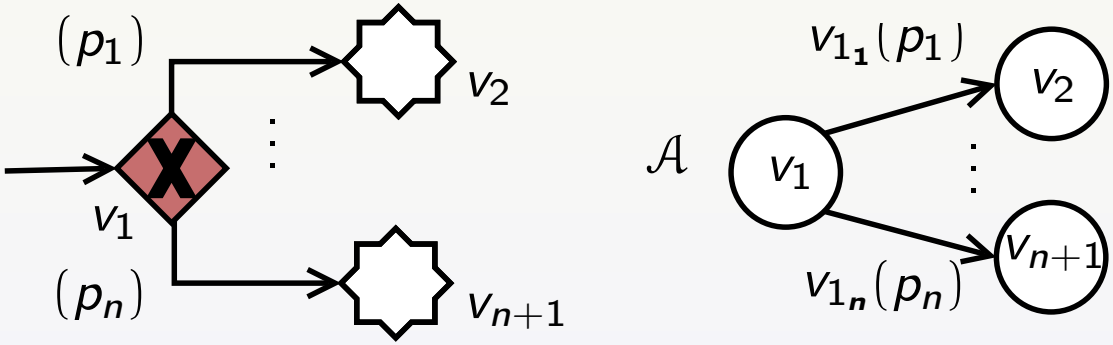
From BPMN Objects to SAN Elementary Models

Start Event

Atomic Task



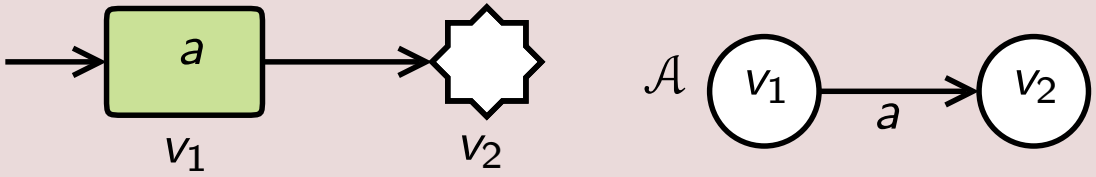
Exc. Gateway 1



From BPMN Objects to SAN Elementary Models

Start Event

Atomic Task



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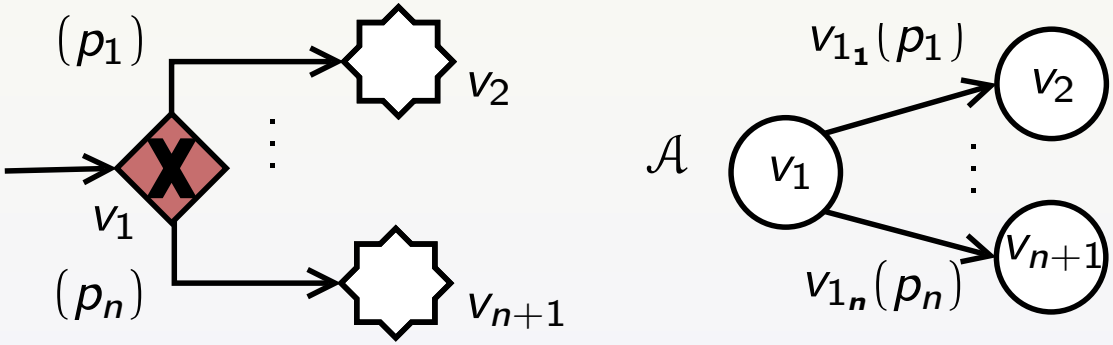
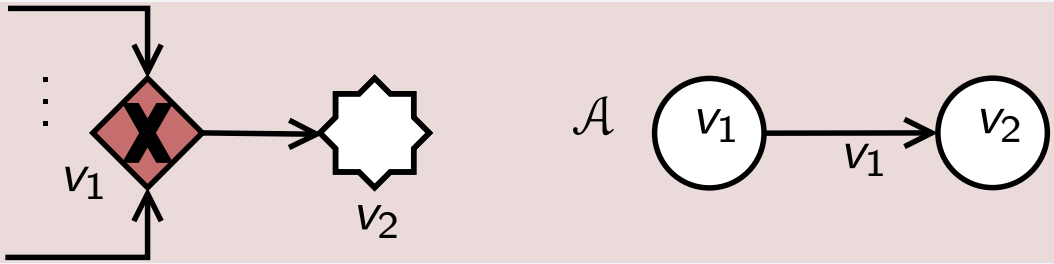
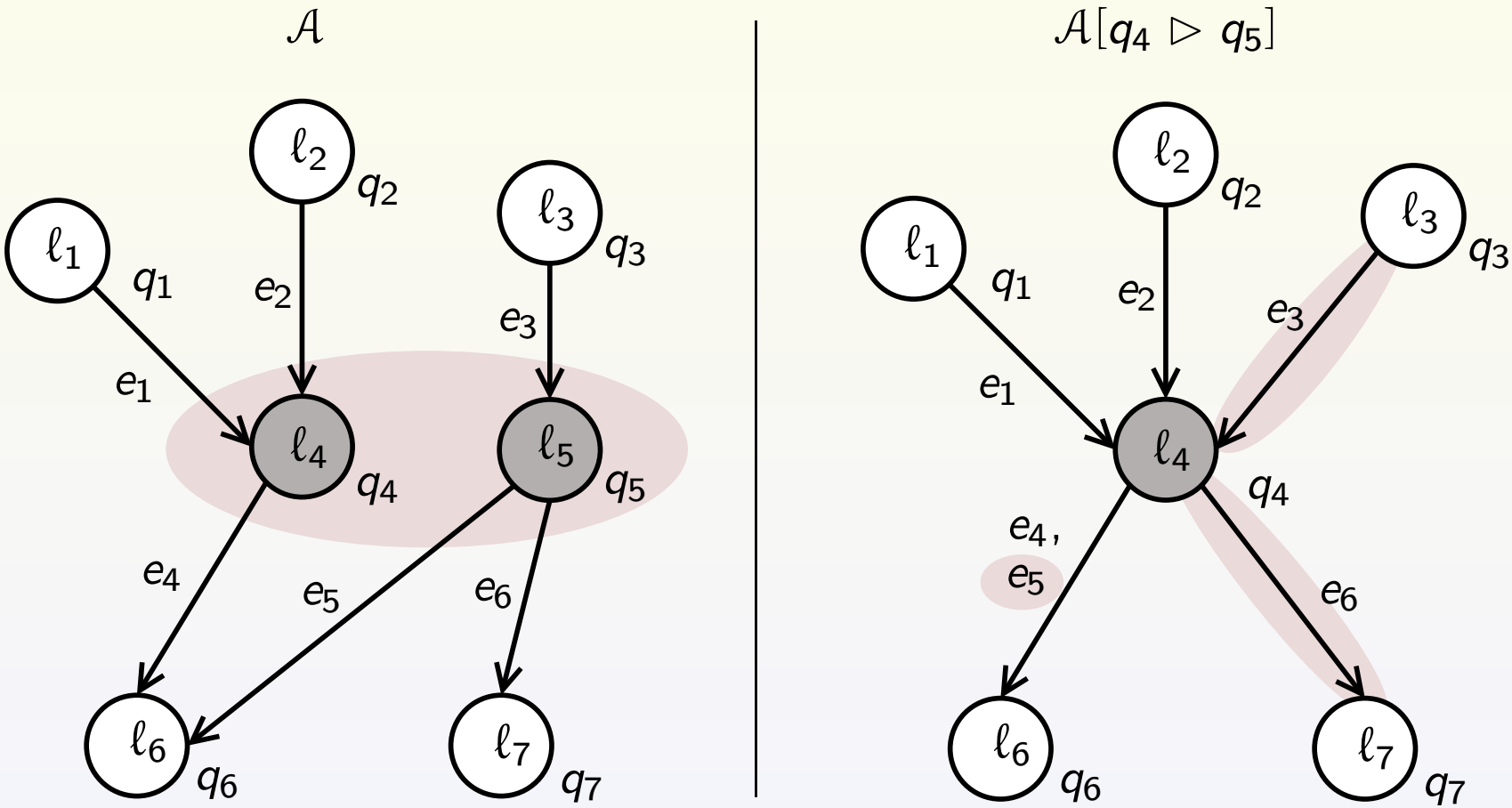


Exc. Gateway 2



Operation 1 – State Merge ($\triangleright$)



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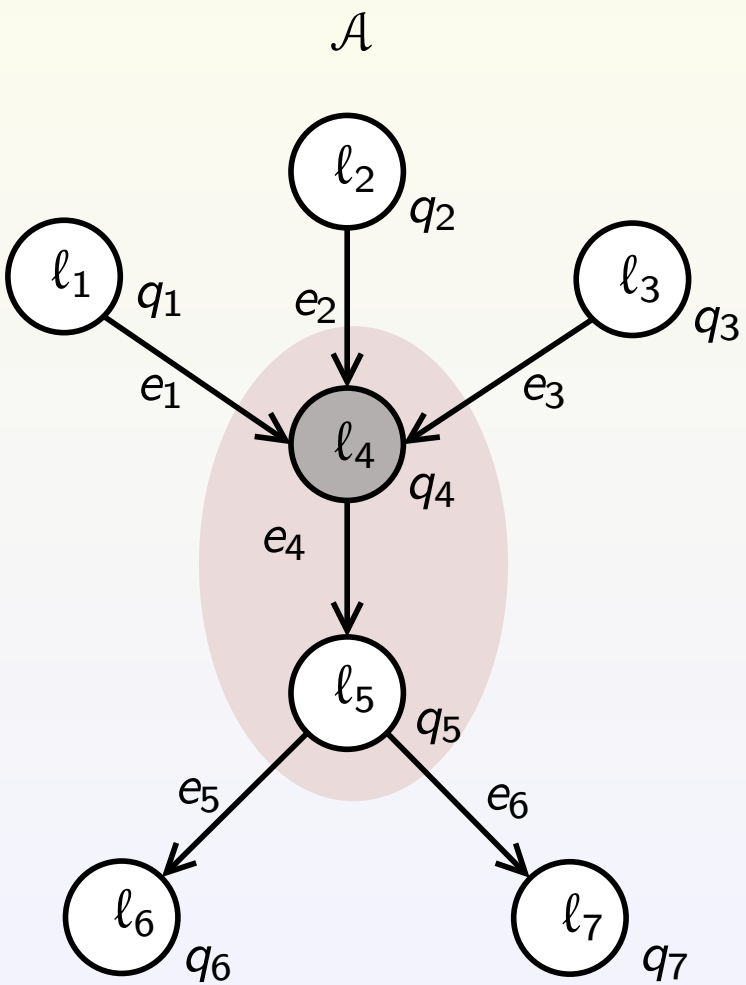
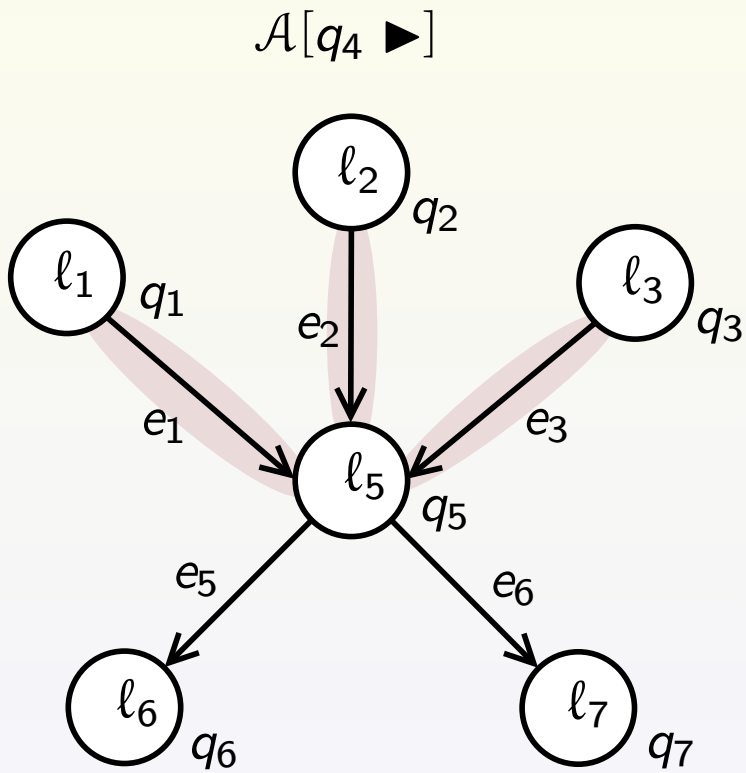
Operation 2 – State Suppression (▶)

Condition: $|outputs(q_4)| = 1$





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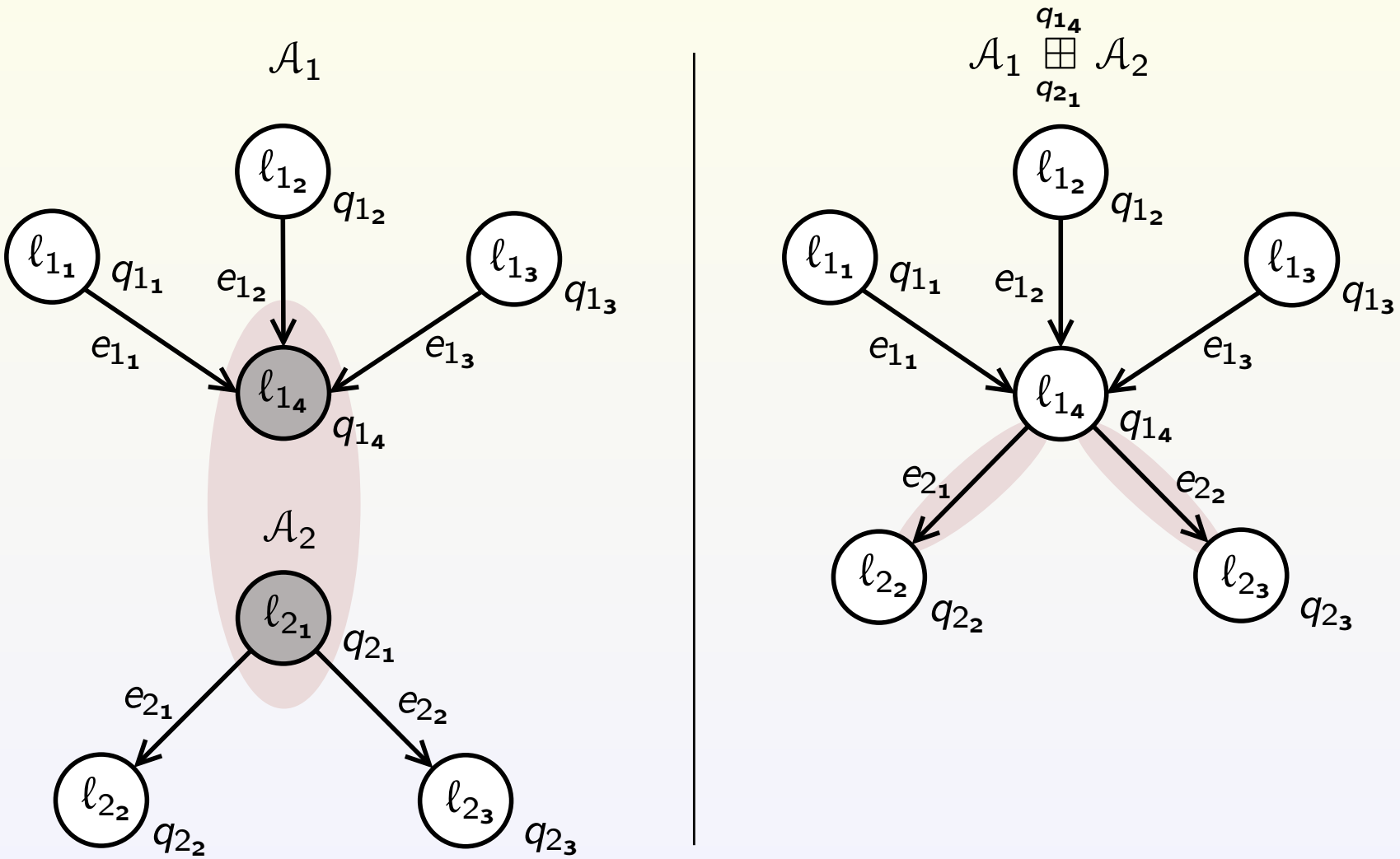
Operation 3 – Automata Concatenation (⊞)



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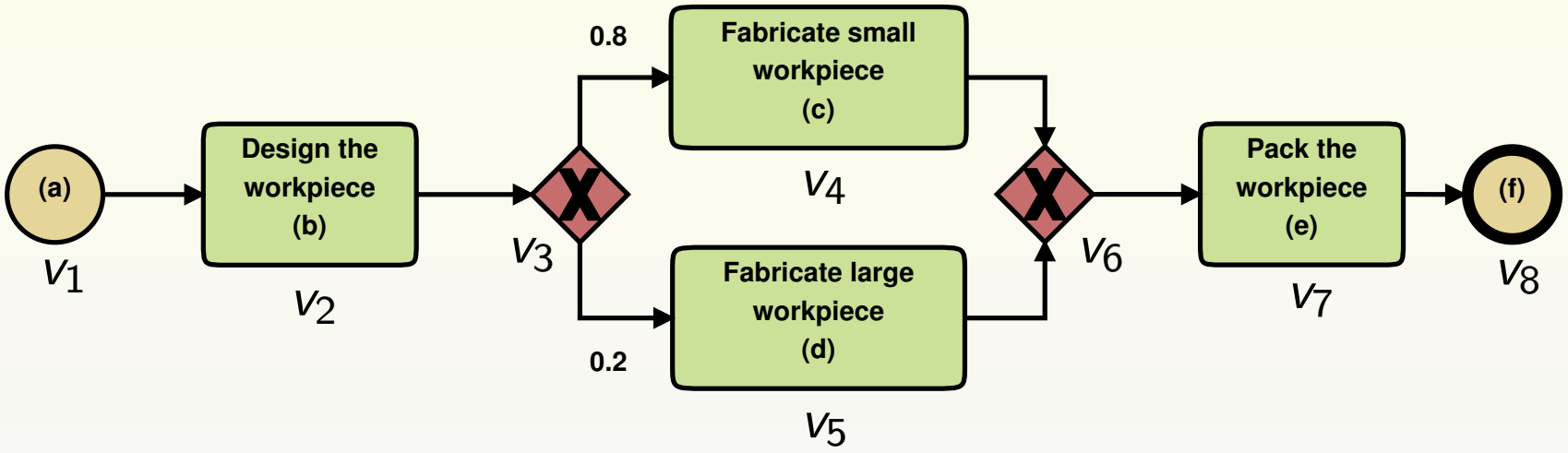
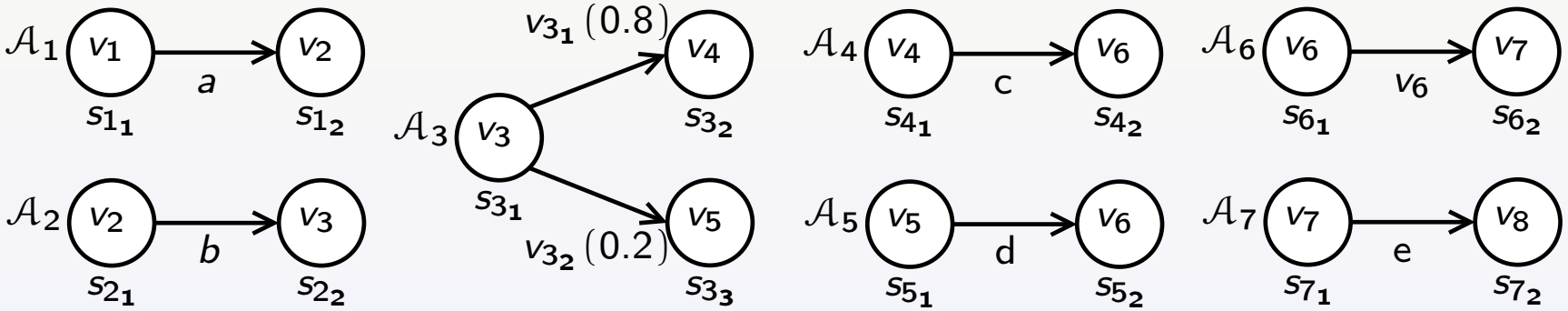
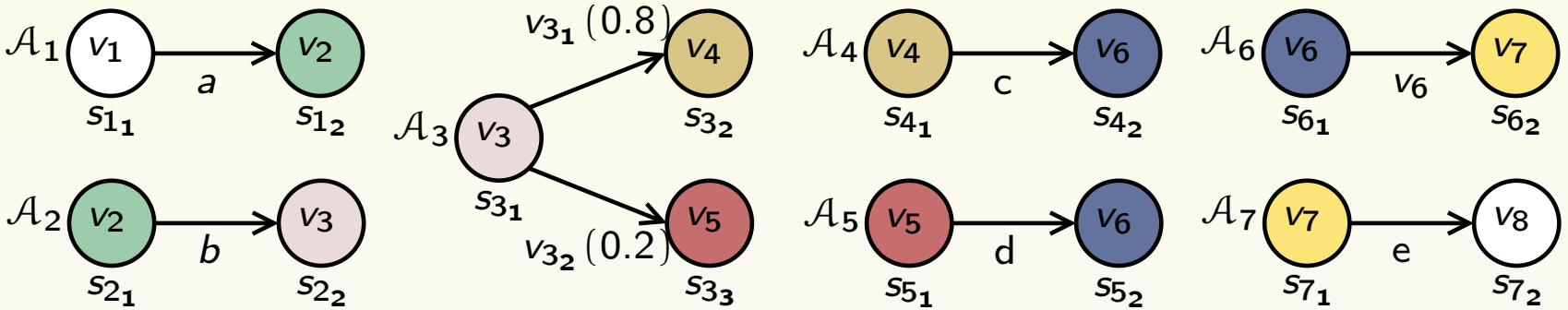
Conversion Example – Vertex Mappings

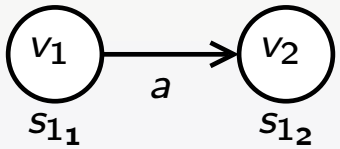




Conversion Example – Reduction Operations



$\boxed{\mathcal{A}_1}$



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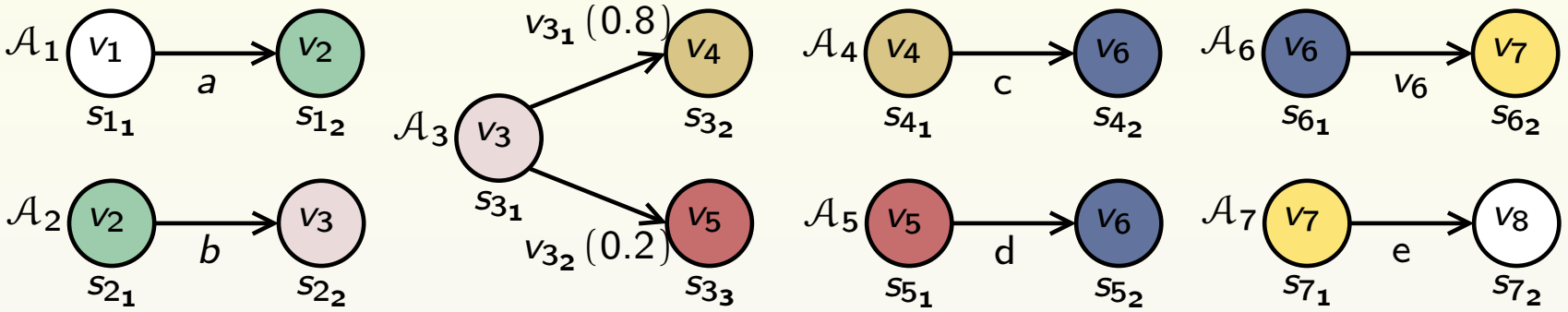
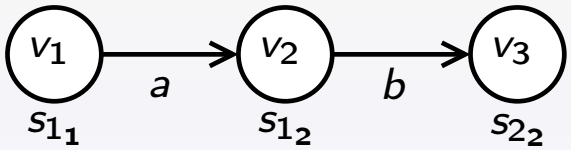


$$\mathcal{A}_1 \boxplus_{s2_1}^{s1_2} \mathcal{A}_2$$



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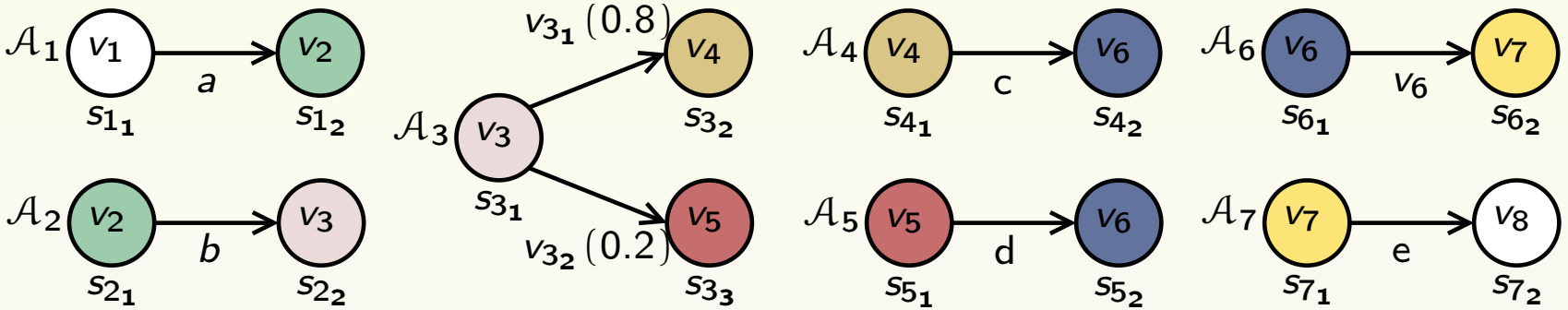
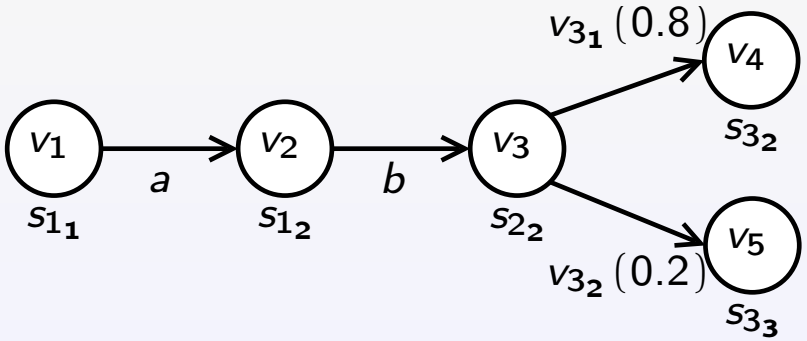


$$\mathcal{A}_1 \boxplus_{s_{2_1}}^{s_{1_2}} \mathcal{A}_2 \boxplus_{s_{3_1}}^{s_{2_2}} \mathcal{A}_3$$



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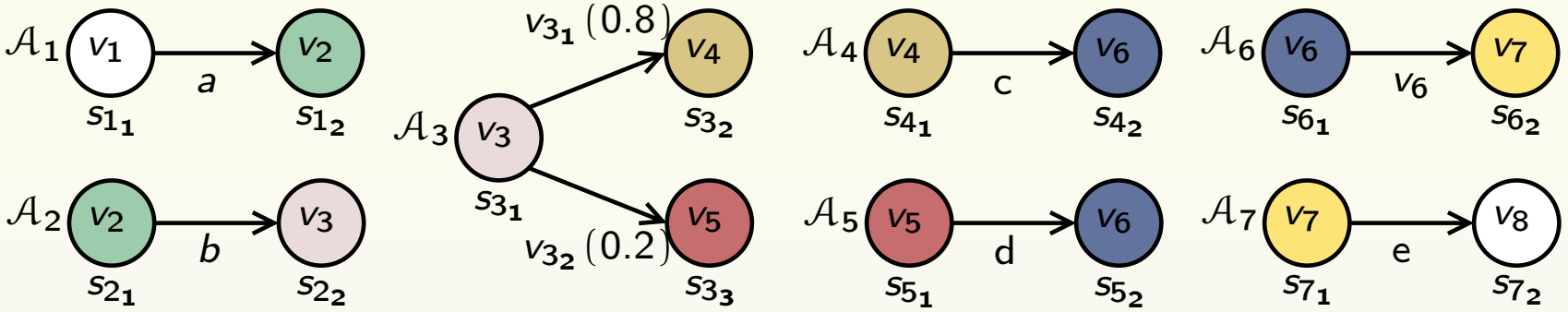
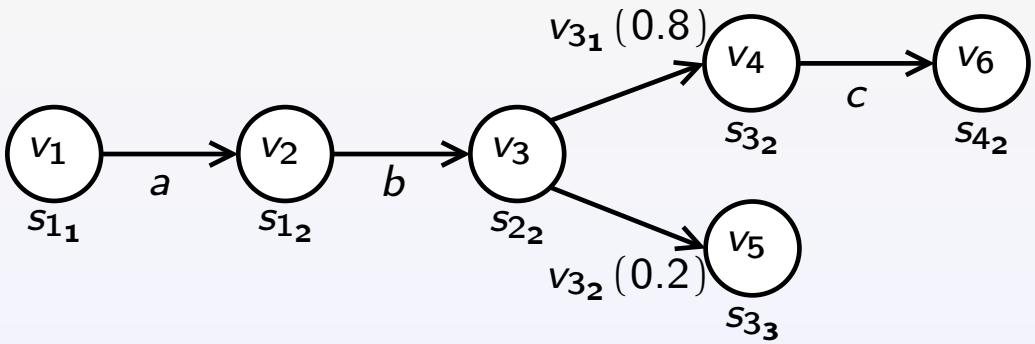


$$\mathcal{A}_1 \underset{s2_1}{\overset{s1_2}{\boxplus}} \mathcal{A}_2 \underset{s3_1}{\overset{s2_2}{\boxplus}} \mathcal{A}_3 \underset{s4_1}{\overset{s3_2}{\boxplus}} \mathcal{A}_4$$



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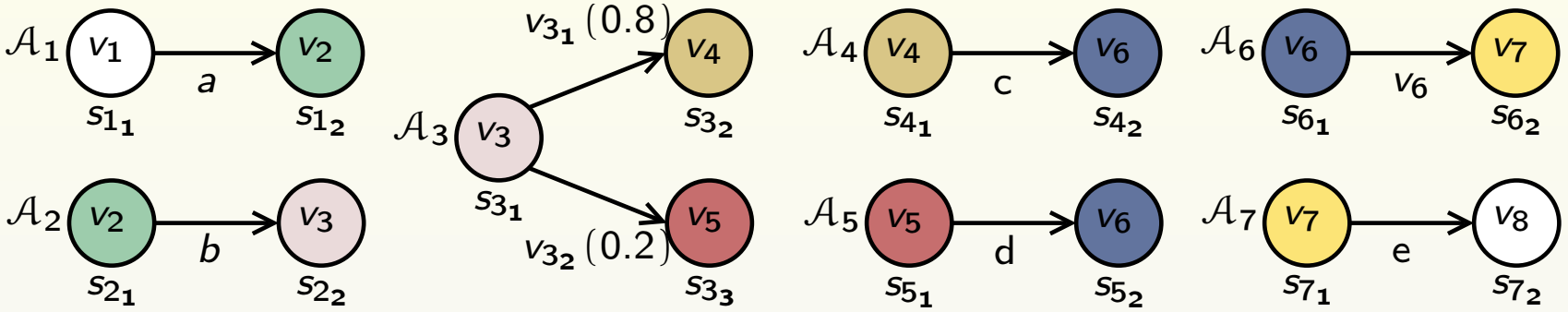
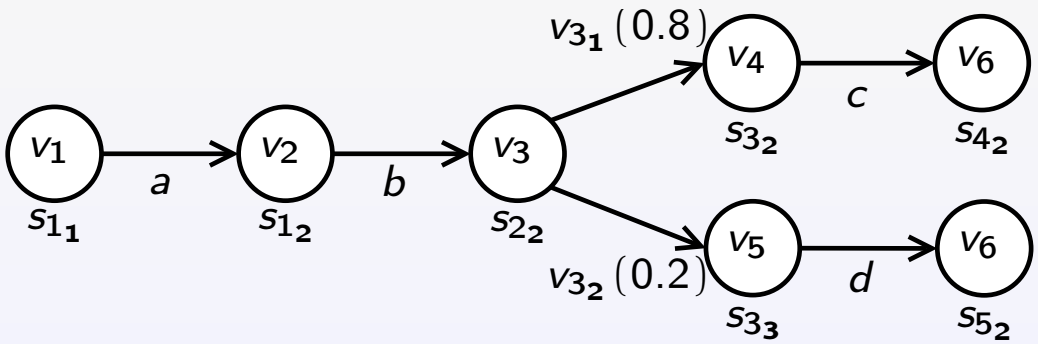


$$\mathcal{A}_1 \overset{s1_2}{\underset{s2_1}{\boxplus}} \mathcal{A}_2 \overset{s2_2}{\underset{s3_1}{\boxplus}} \mathcal{A}_3 \overset{s3_2}{\underset{s4_1}{\boxplus}} \mathcal{A}_4 \overset{s3_3}{\underset{s5_1}{\boxplus}} \mathcal{A}_5$$



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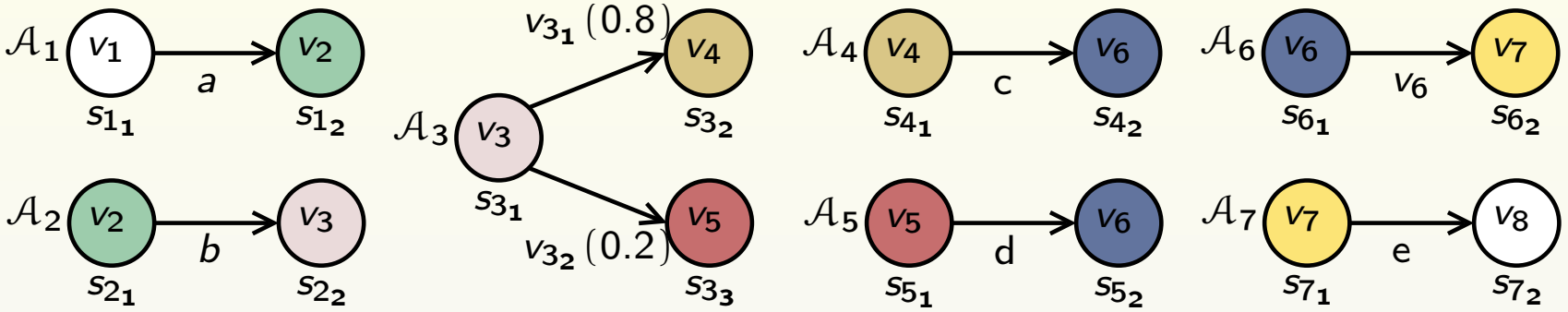
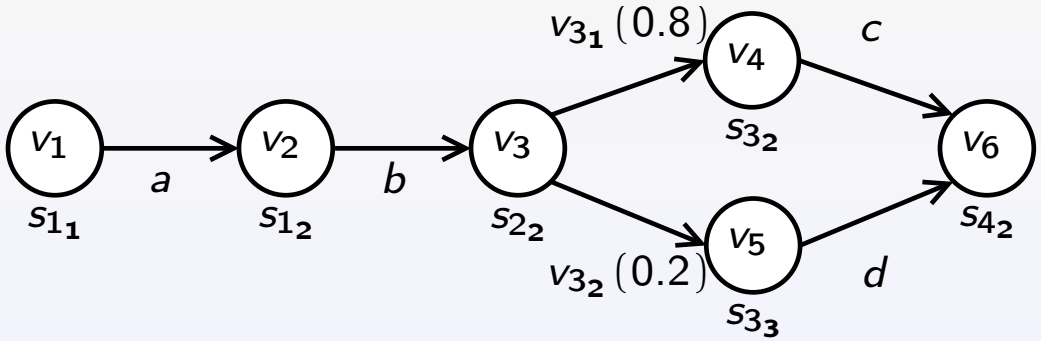


$$(\mathcal{A}_1 \boxplus_{s2_1}^{s1_2} \mathcal{A}_2 \boxplus_{s3_1}^{s2_2} \mathcal{A}_3 \boxplus_{s4_1}^{s3_2} \mathcal{A}_4 \boxplus_{s5_1}^{s3_3} \mathcal{A}_5)[s4_2 \triangleright s5_2]$$



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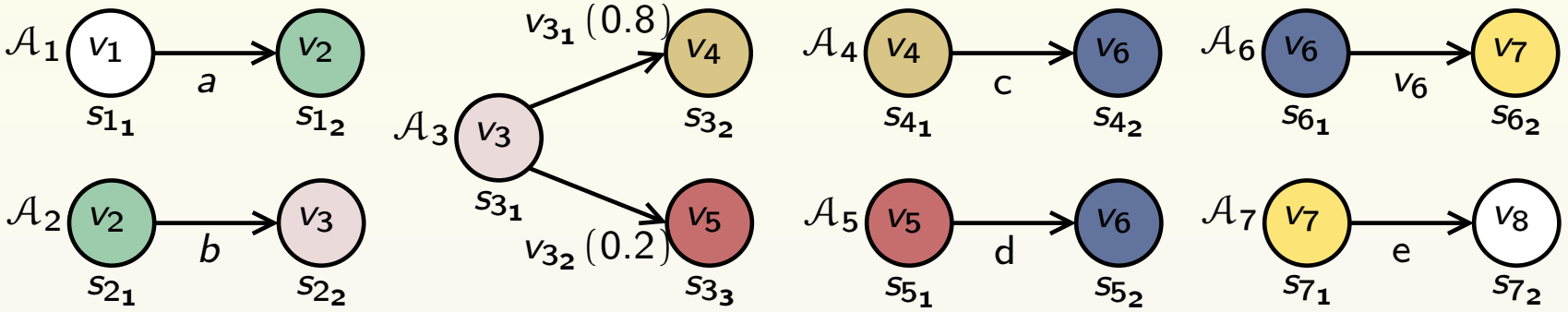
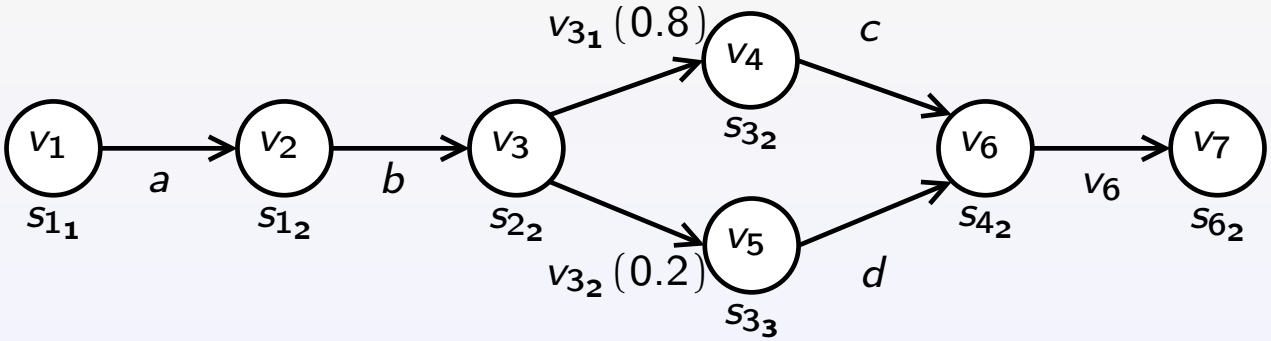


$$(\mathcal{A}_1 \underset{s2_1}{\overset{s1_2}{\boxplus}} \mathcal{A}_2 \underset{s3_1}{\overset{s2_2}{\boxplus}} \mathcal{A}_3 \underset{s4_1}{\overset{s3_2}{\boxplus}} \mathcal{A}_4 \underset{s5_1}{\overset{s3_3}{\boxplus}} \mathcal{A}_5)[s4_2 \triangleright s5_2] \underset{s6_1}{\overset{s4_2}{\boxplus}} \mathcal{A}_6$$



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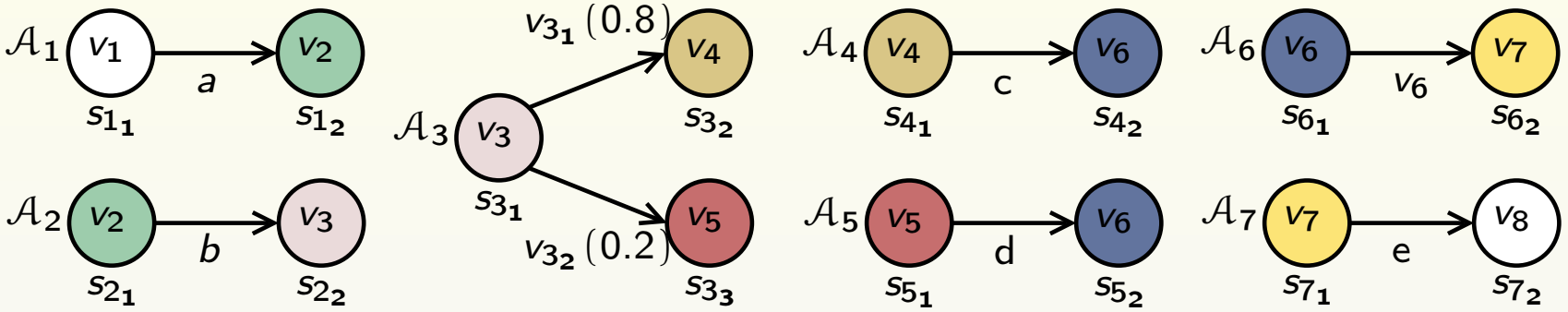
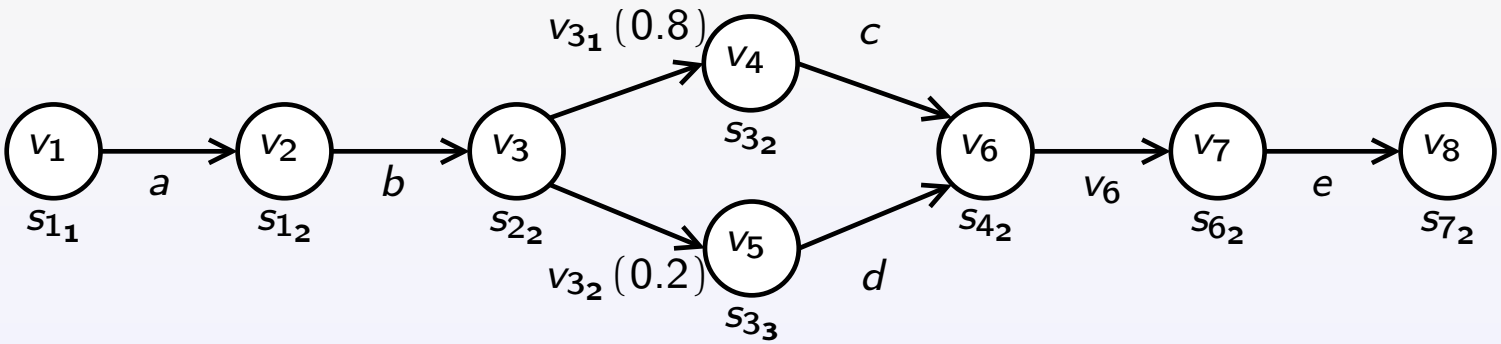
Conversion Example – Reduction Operations



$$(\mathcal{A}_1 \boxplus_{s2_1}^{s1_2} \mathcal{A}_2 \boxplus_{s3_1}^{s2_2} \mathcal{A}_3 \boxplus_{s4_1}^{s3_2} \mathcal{A}_4 \boxplus_{s5_1}^{s3_3} \mathcal{A}_5)[s_{4_2} \rhd s_{5_2}] \boxplus_{s6_1}^{s4_2} \mathcal{A}_6 \boxplus_{s7_1}^{s6_2} \mathcal{A}_7$$



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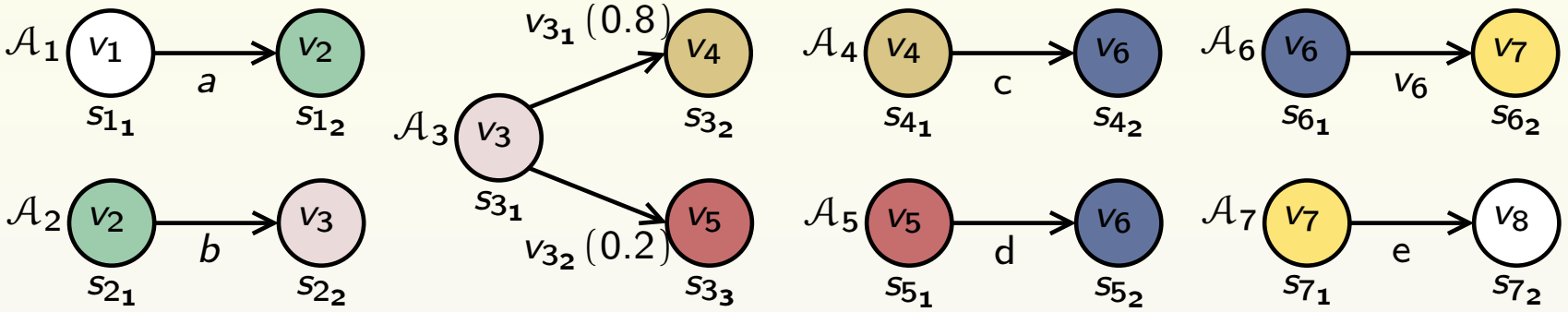
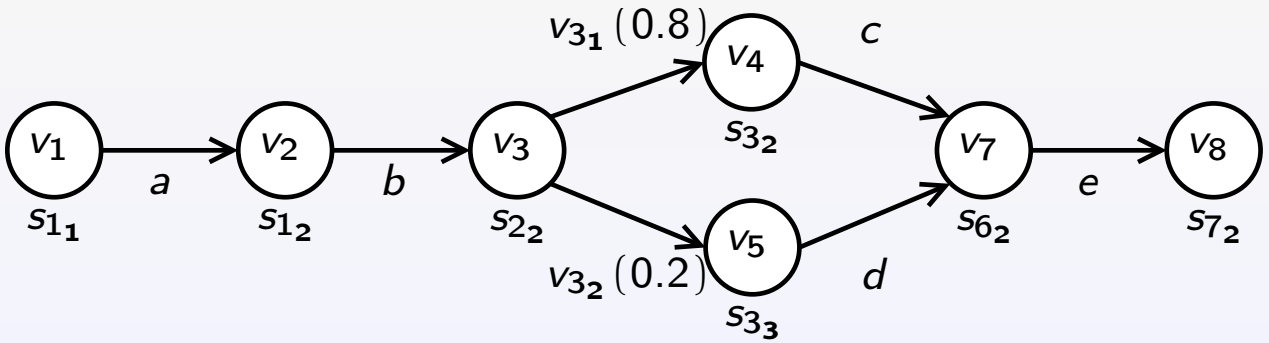
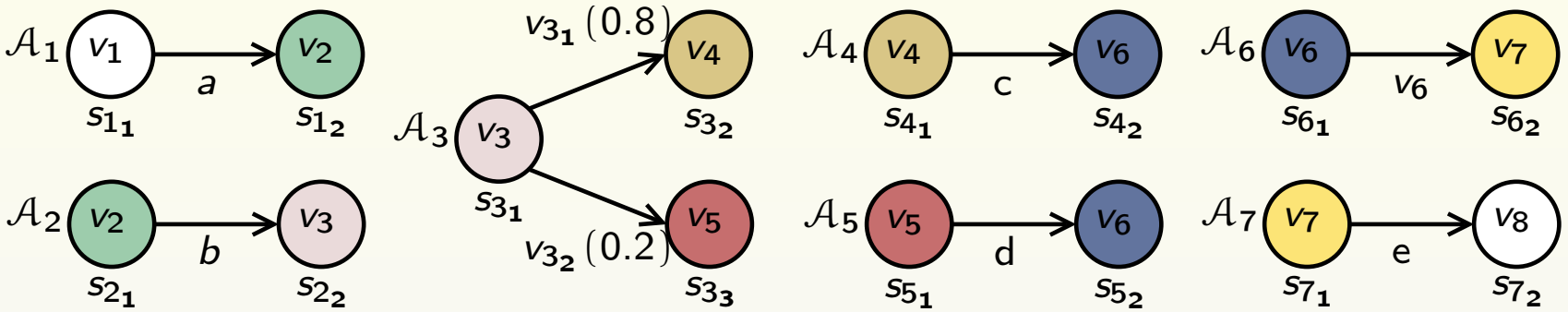
Conversion Example – Reduction Operations



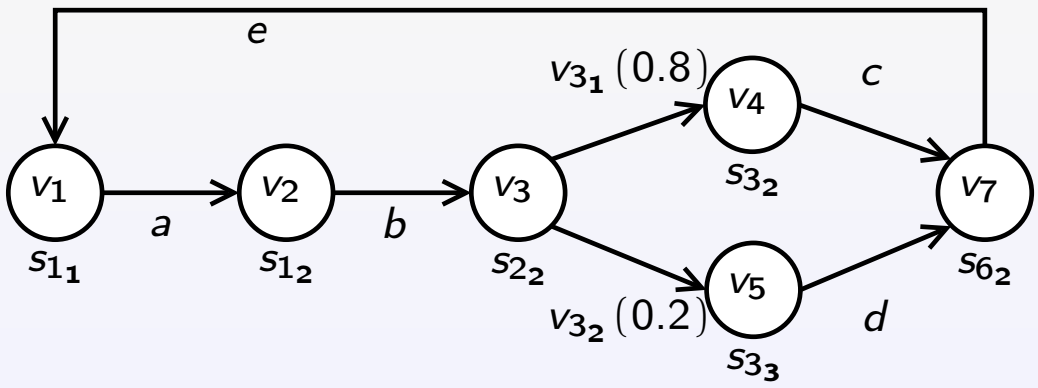
$$((\mathcal{A}_1 \boxplus_{s2_1}^{s1_2} \mathcal{A}_2 \boxplus_{s3_1}^{s2_2} \mathcal{A}_3 \boxplus_{s4_1}^{s3_2} \mathcal{A}_4 \boxplus_{s5_1}^{s3_3} \mathcal{A}_5)[s_{4_2} \rhd s_{5_2}] \boxplus_{s6_1}^{s4_2} \mathcal{A}_6 \boxplus_{s7_1}^{s6_2} \mathcal{A}_7)[s_{4_2} \blacktriangleright]$$



Conversion Example – Reduction Operations



$$((\mathcal{A}_1 \boxplus_{s_{2_1}}^{s_{1_2}} \mathcal{A}_2 \boxplus_{s_{3_1}}^{s_{2_2}} \mathcal{A}_3 \boxplus_{s_{4_1}}^{s_{3_2}} \mathcal{A}_4 \boxplus_{s_{5_1}}^{s_{3_3}} \mathcal{A}_5)[s_{4_2} \rhd s_{5_2}] \boxplus_{s_{6_1}}^{s_{4_2}} \mathcal{A}_6 \boxplus_{s_{7_1}}^{s_{6_2}} \mathcal{A}_7)[s_{4_2} \blacktriangleright][s_{1_1} \rhd s_{7_2}]$$



Missing: information about event rates

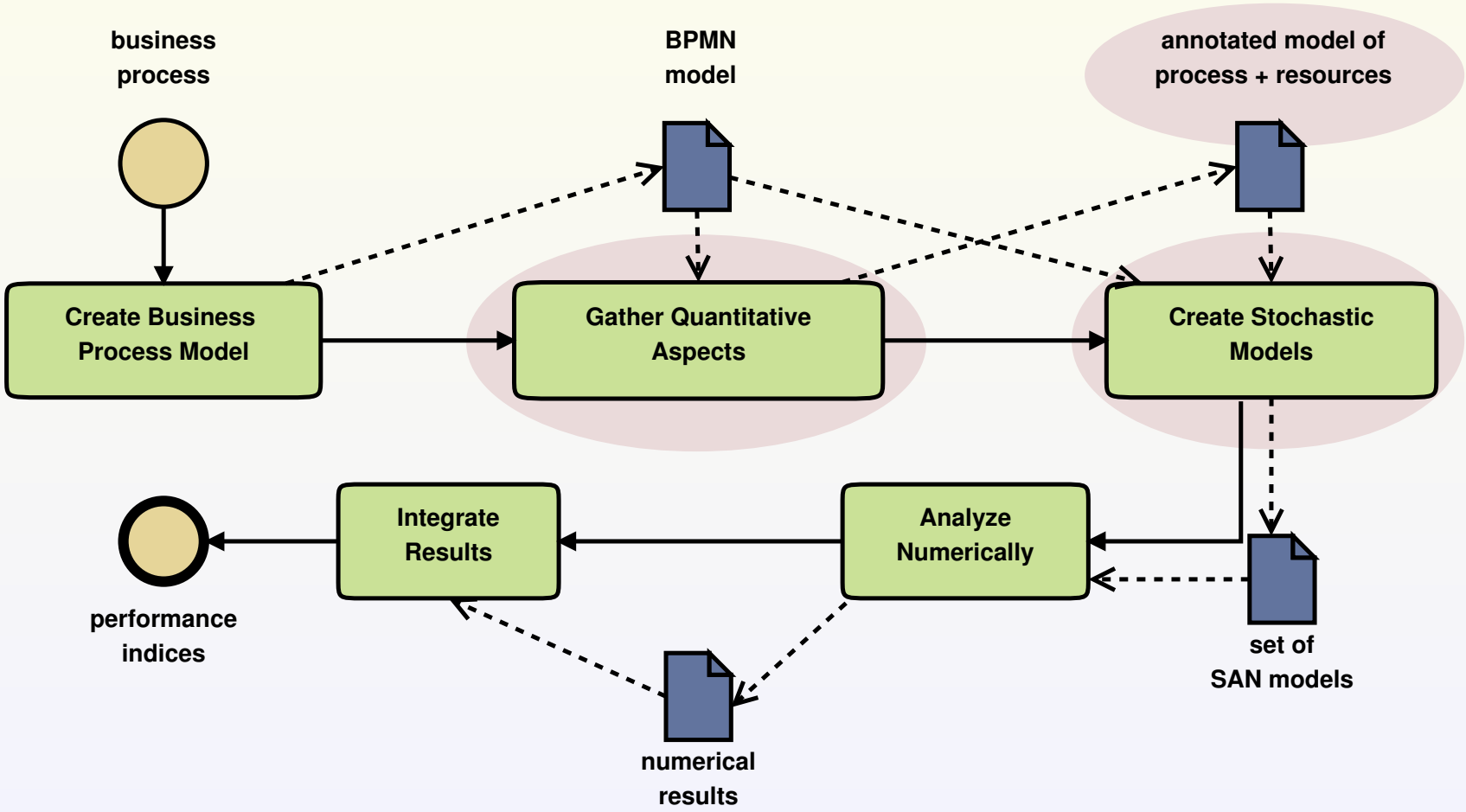
- Rates are related to the **execution time** of tasks
- Tasks **are performed by** resources or **depend on** resources to be executed

Resource Management

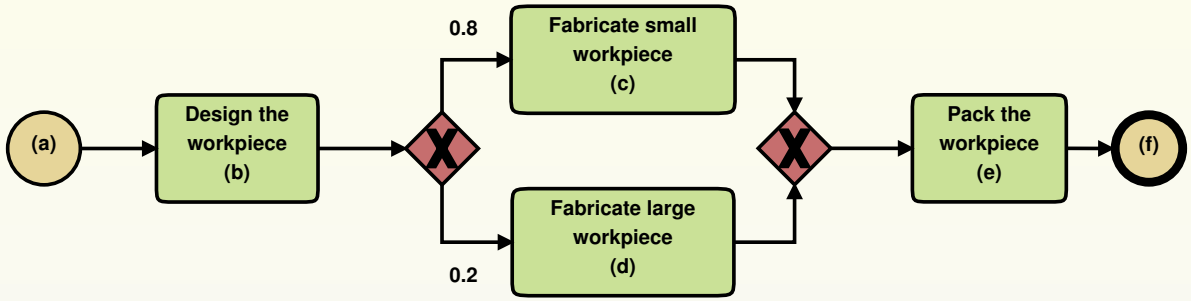
The BP model lacks information about resources:

- What are the resources required in the business process?
- How many are available?
- What is their work capacity?
- How are they accessed?

Part III: Enriching BP Models with Resource Info



Resources and Requirements of the MS Process



4 Designers, 2 CNC1, 1 CNC2, 1 Painting Machine, 1 Packer

- Designers work in pairs and take 4h to make a workpiece model
- 1 order = 20 small pieces or 10 big pieces
- 1 small piece = 3 small blocks; 1 big piece = 2 big blocks
- 1 big block $\approx$ 2 small blocks
- CNC1 $\Rightarrow$ 6 small blocks/h; CNC2 $\Rightarrow$ 2 big blocks/h
- Painting machine paints 10 small pieces per hour
- Packer takes 1h to pack 1 order

Declaration of Available Resources

Resource

([**resource id**], [**quantity**], [**work capacity**], [**access discipline**])

Examples of access disciplines:

- FIFO, LIFO, Priority System, **Random Choice**, **Time Sharing**

Resource set (RS) of the Machine Shop process

$$
\begin{aligned}
RS = \{ \quad & (\text{“Designer”};\ 4;\ 0.125;\text{“Random Choice”}),\\
& (\text{“CNC1”};\ 2;\ 6.0;\text{“Random Choice”}),\\
& (\text{“CNC2”};\ 1;\ 2.0;\text{“Random Choice”})\\
& (\text{“Painting”};\ 1;\ 10.0;\text{“Time Sharing”})\\
& (\text{“Packer”};\ 1;\ 1.0;\text{“Random Choice”}) \quad \}
\end{aligned}
$$

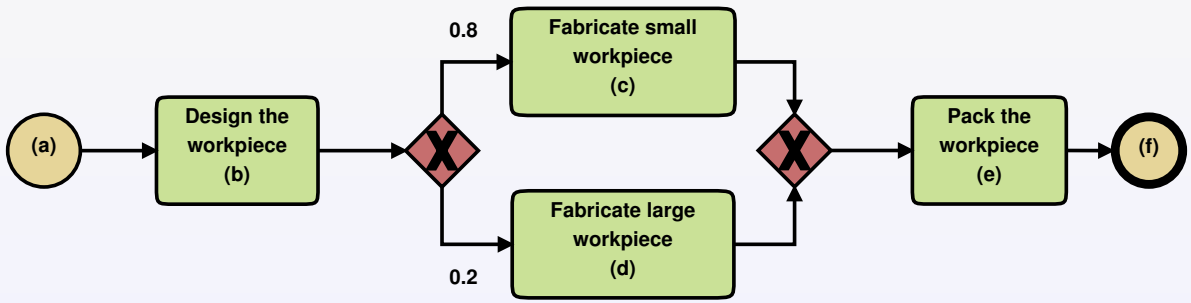
Declaration of Resource Requirements I

Single Resource Requirement (*SRR*)

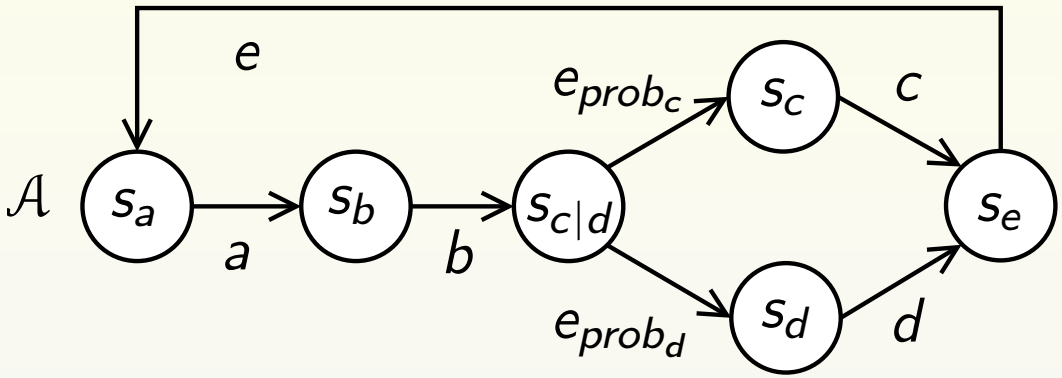
([**resource id**], [**quantity of work**])

Resource requirements (*RR*) of tasks in the MS process

$$
\begin{aligned}
RR(b) &= (\text{“Designer”};\ 0.5) \wedge (\text{“Designer”};\ 0.5) \\
RR(c) &= ((\text{“CNC1”};\ 60.0) \vee (\text{“CNC2”};\ 30.0)) \wedge (\text{“Painting”};\ 60.0) \\
RR(d) &= (\text{“CNC2”};\ 20.0) \wedge (\text{“Painting”};\ 40.0) \\
RR(e) &= (\text{“Packer”};\ 1.0)
\end{aligned}
$$



Associating Resource Requirements to Tasks



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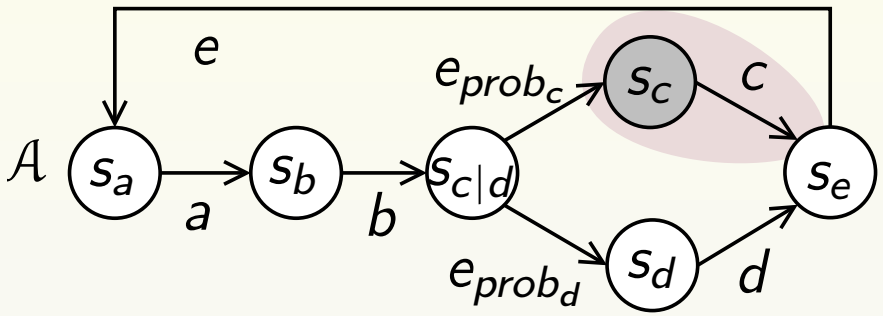
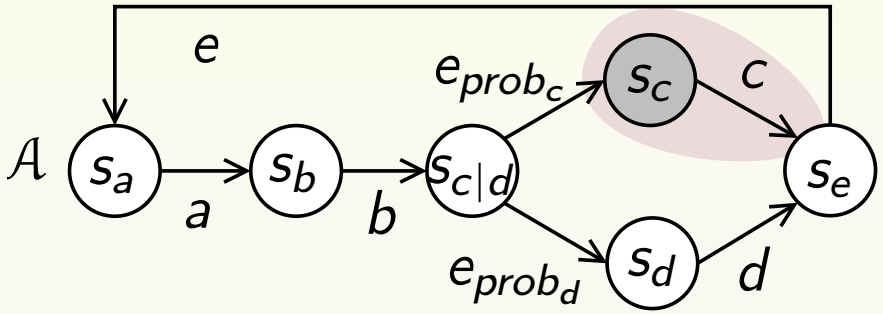
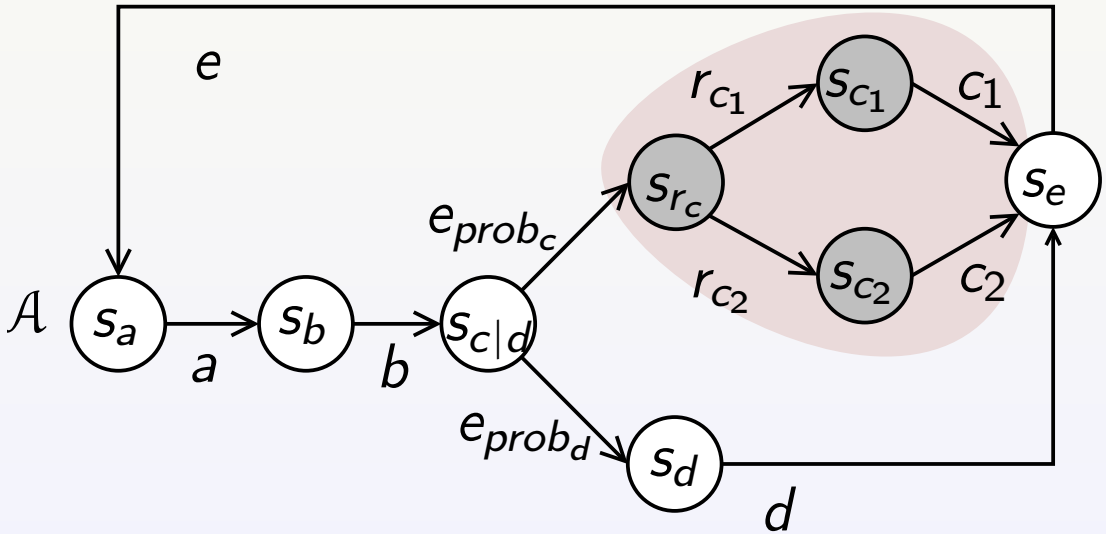


$DRR(c)$
{("CNC1"; 60.0), ("Painting"; 60.0)}
{("CNC2"; 30.0), ("Painting"; 60.0)}

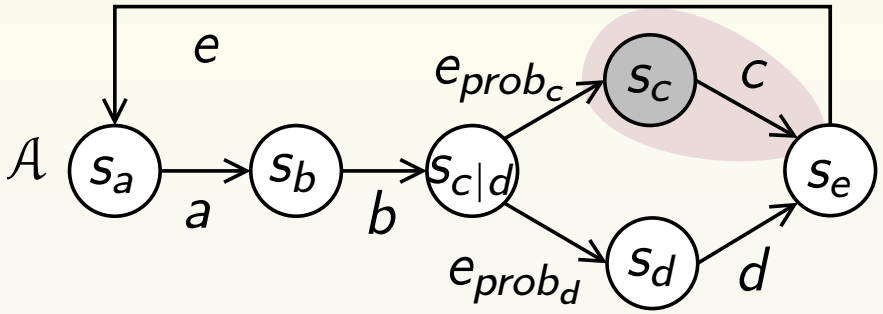
Associating Resource Requirements to Tasks



$DRR(c)$
{("CNC1"; 60.0), ("Painting"; 60.0)}
{("CNC2"; 30.0), ("Painting"; 60.0)}



Associating Resource Requirements to Tasks



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{("CNC1"; 60.0), ("Painting"; 60.0)}
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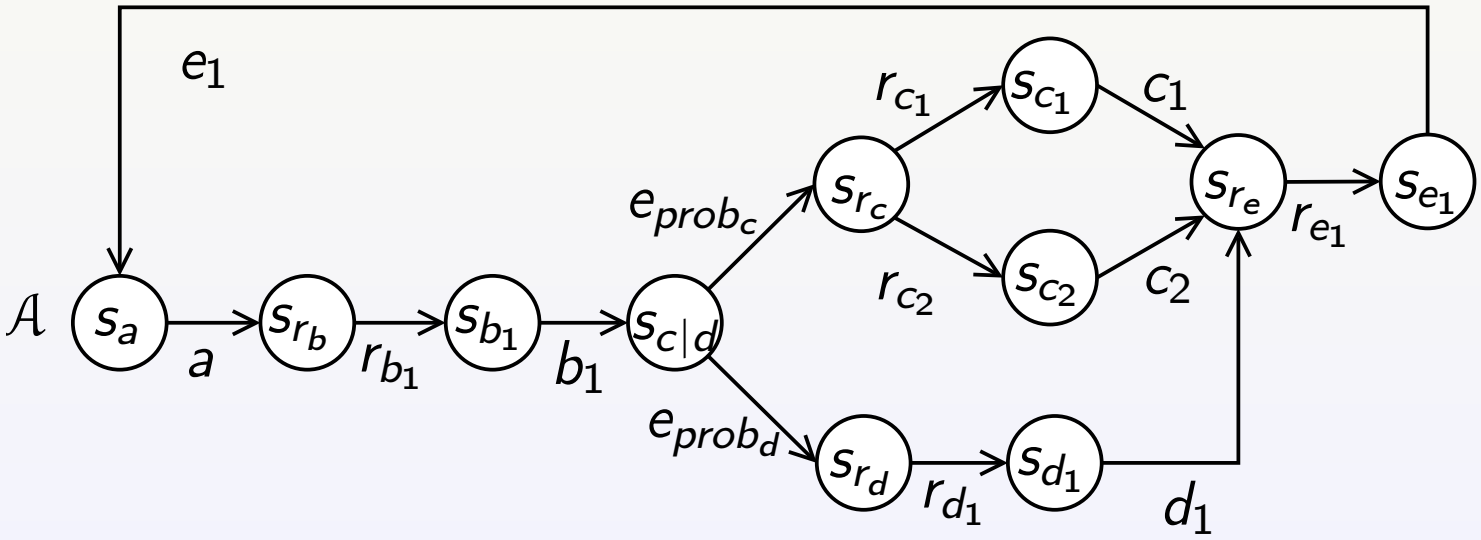
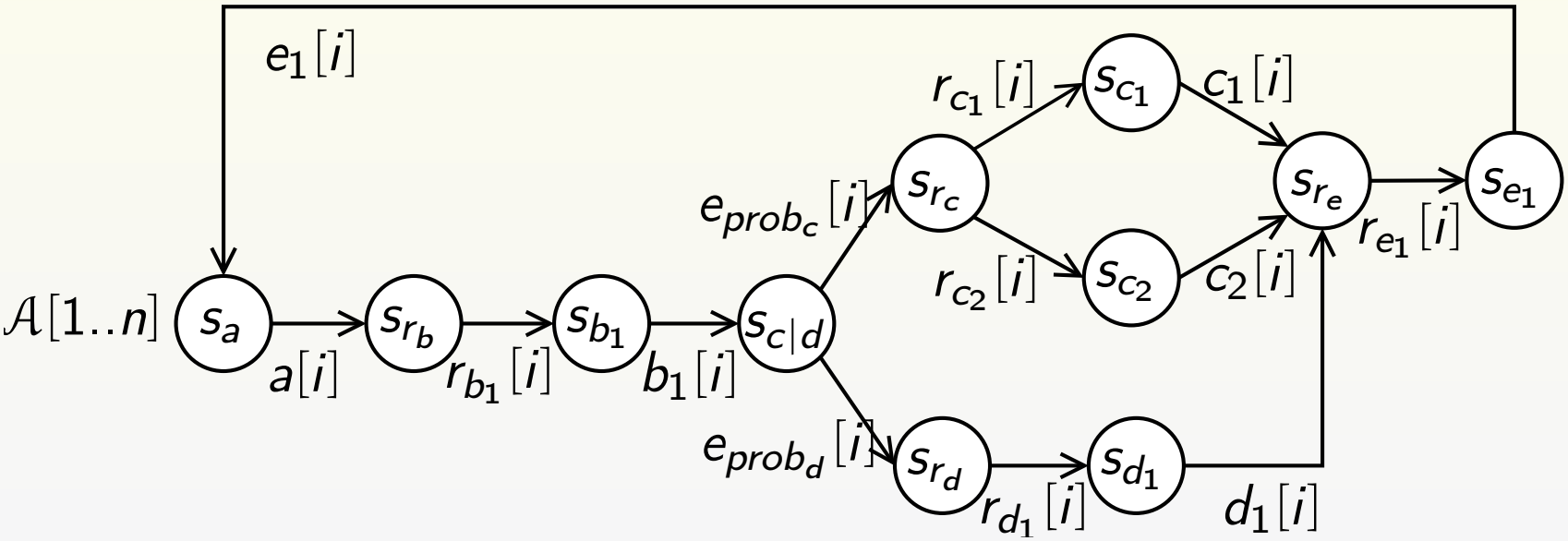
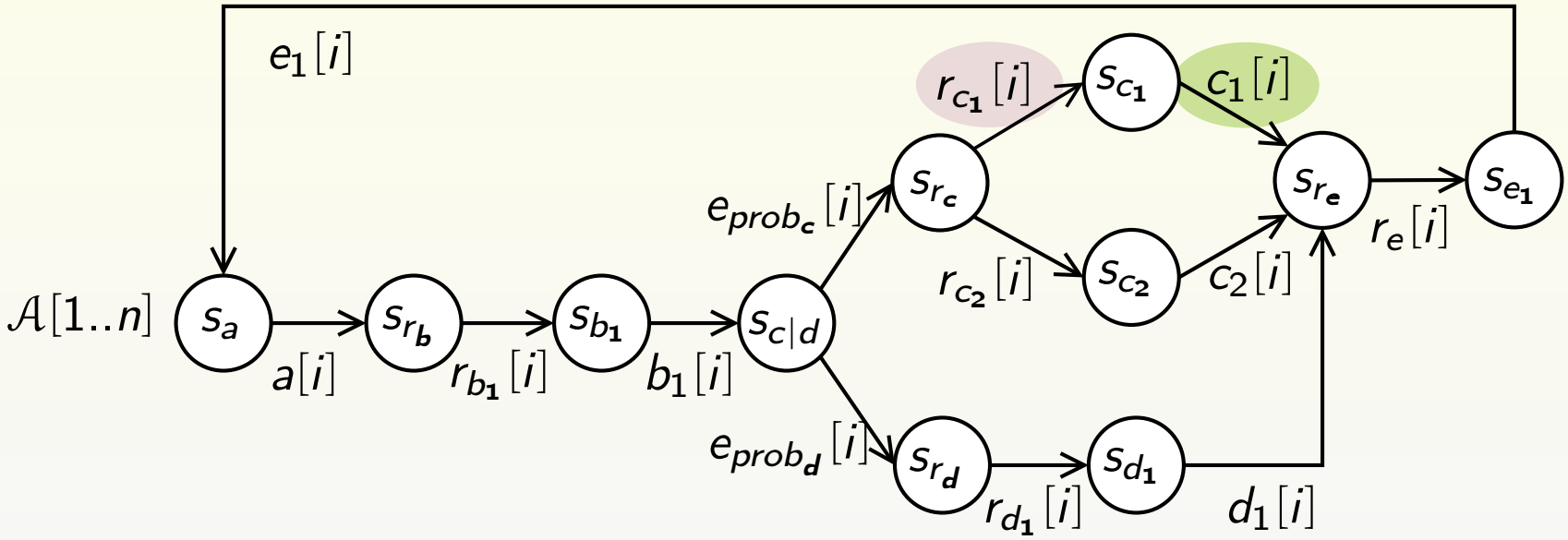
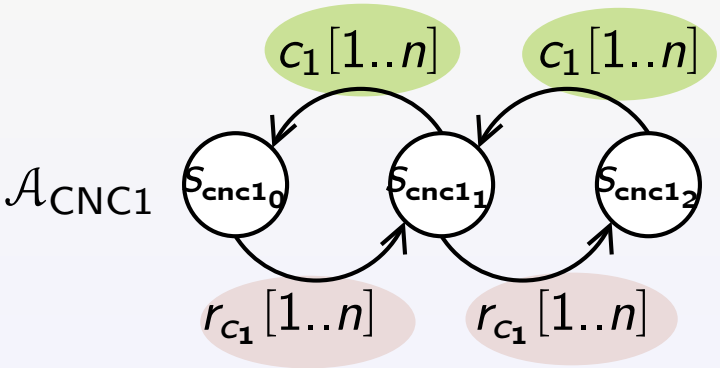


Parallel Instances with Replicated Automata



Random Choice Resources as Automata





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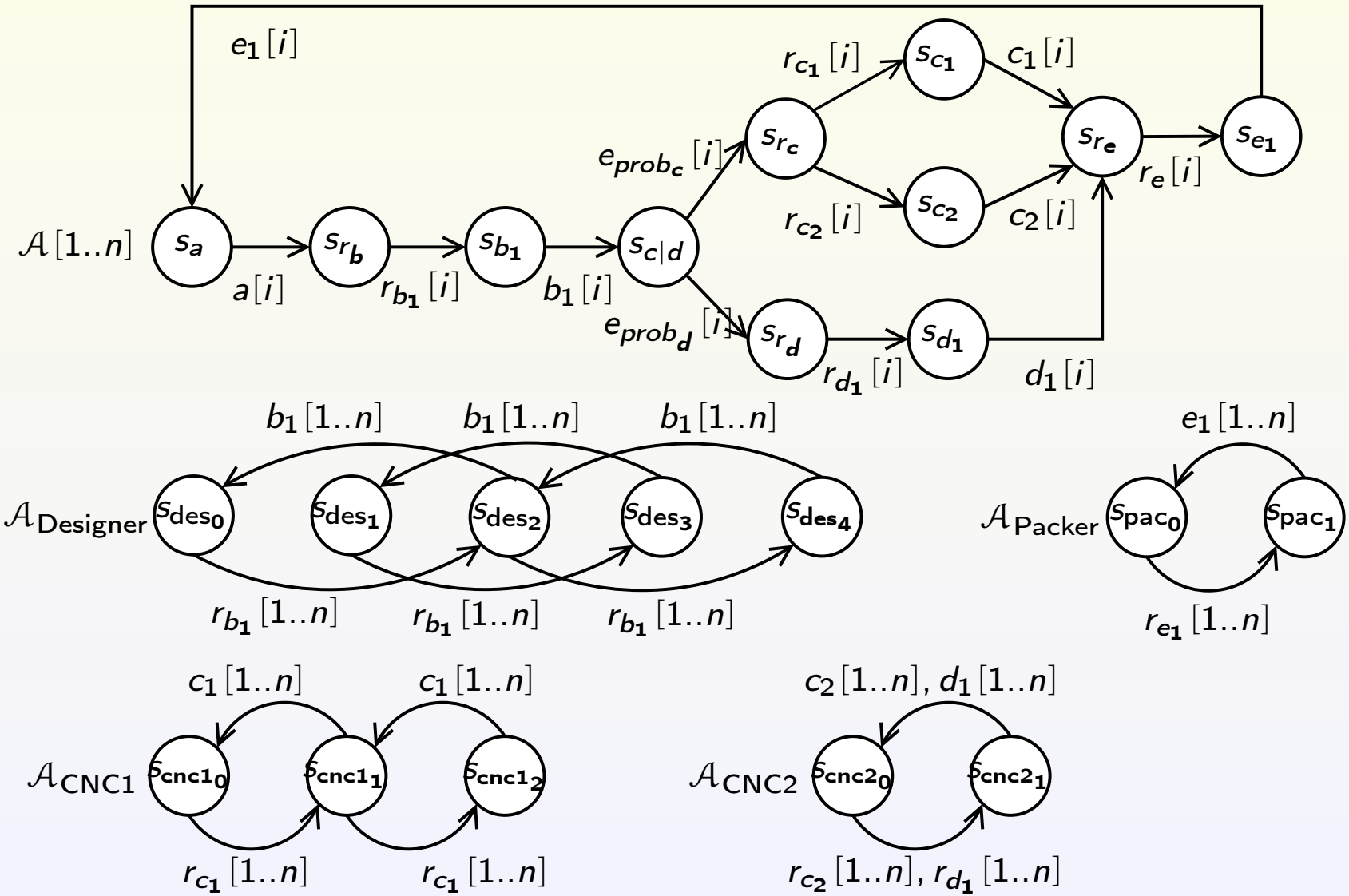
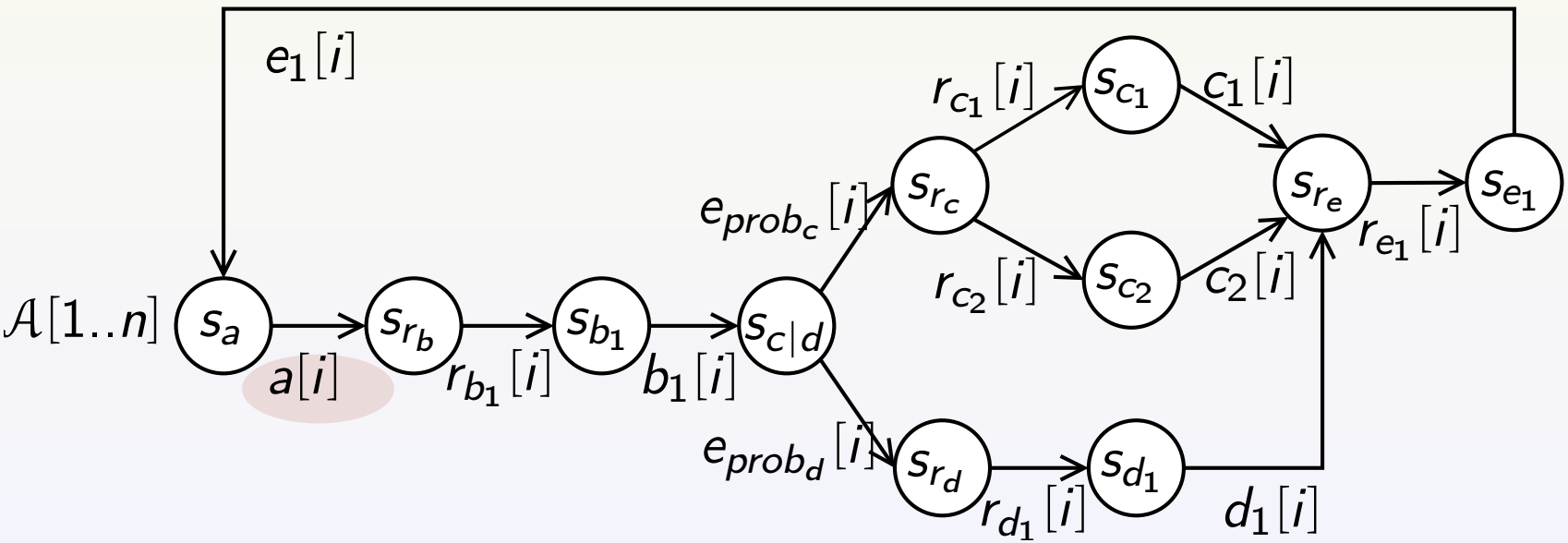


Categories of Events in the Model

- Events associated with BPMN start events
- Events associated with probabilistic routings
- Events to indicate the availability of required resources
- Events to represent the tasks of the BPMN model



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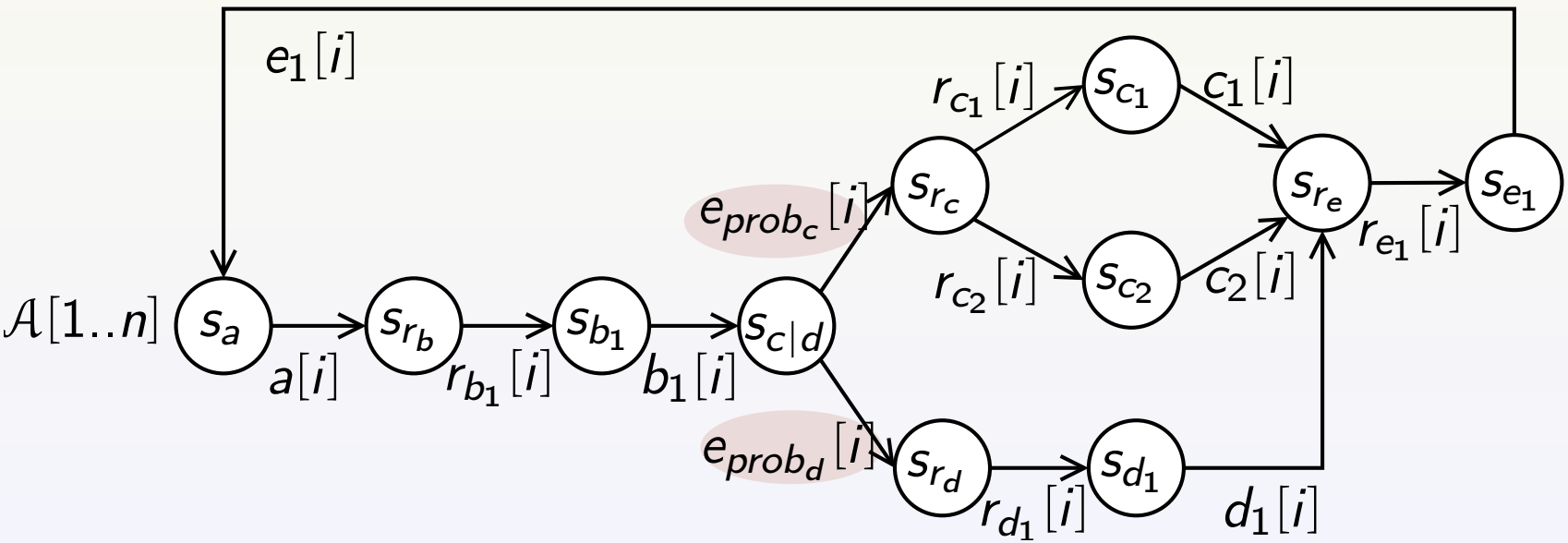

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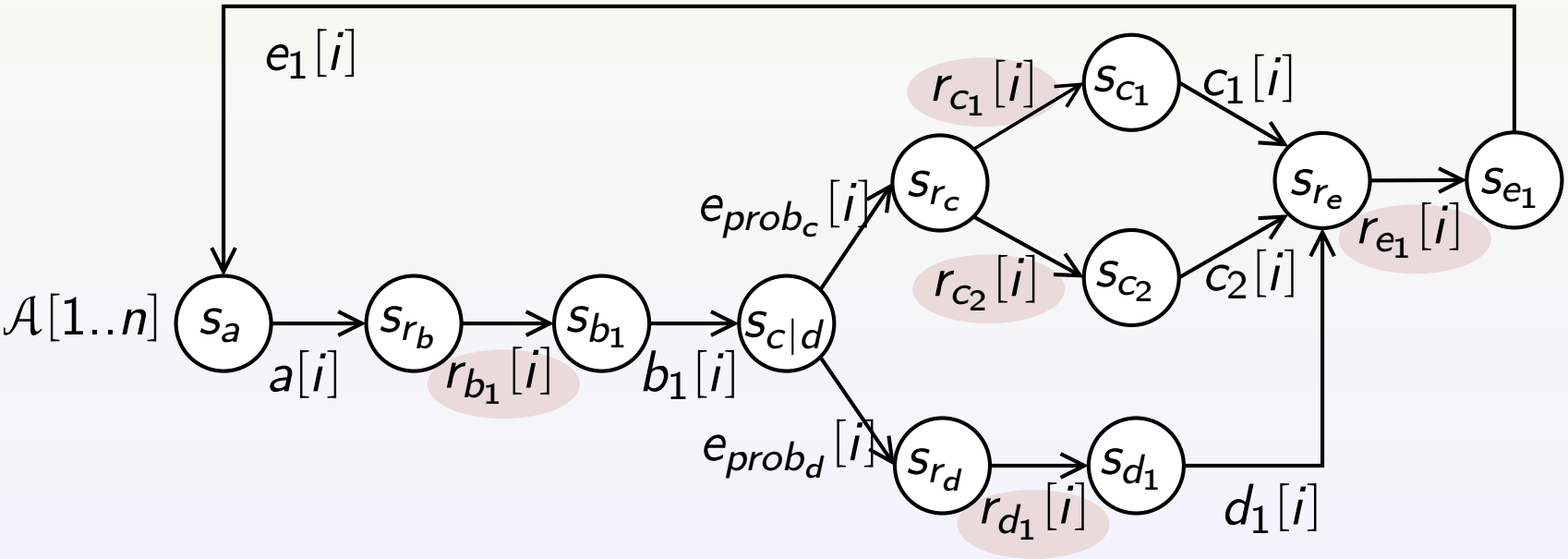

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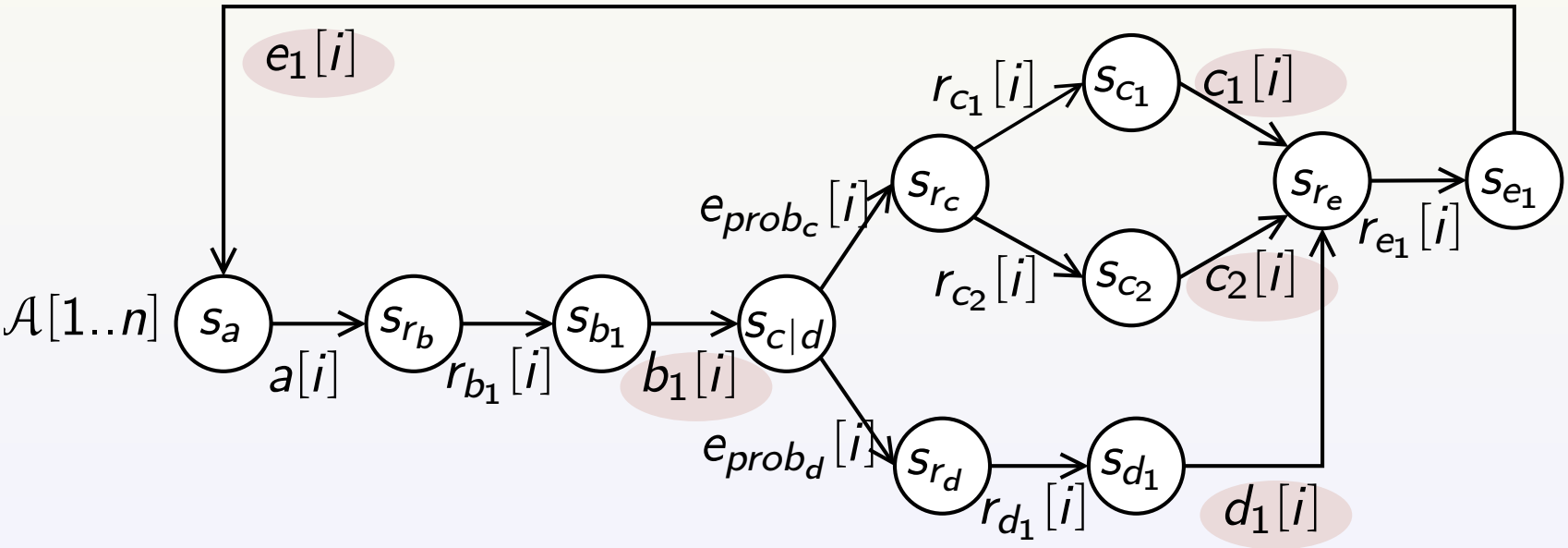


Defining Event Rates I

Start events and probabilistic routing events: constant rates

`rate_a`	=	0.5;	[1 new order each 2 hours]
`rate_prob_c`	=	$0.8 \times \text{rate}_{\text{inst}}$	
`rate_prob_d`	=	$0.2 \times \text{rate}_{\text{inst}}$	

Events to represent the tasks of the BPMN model

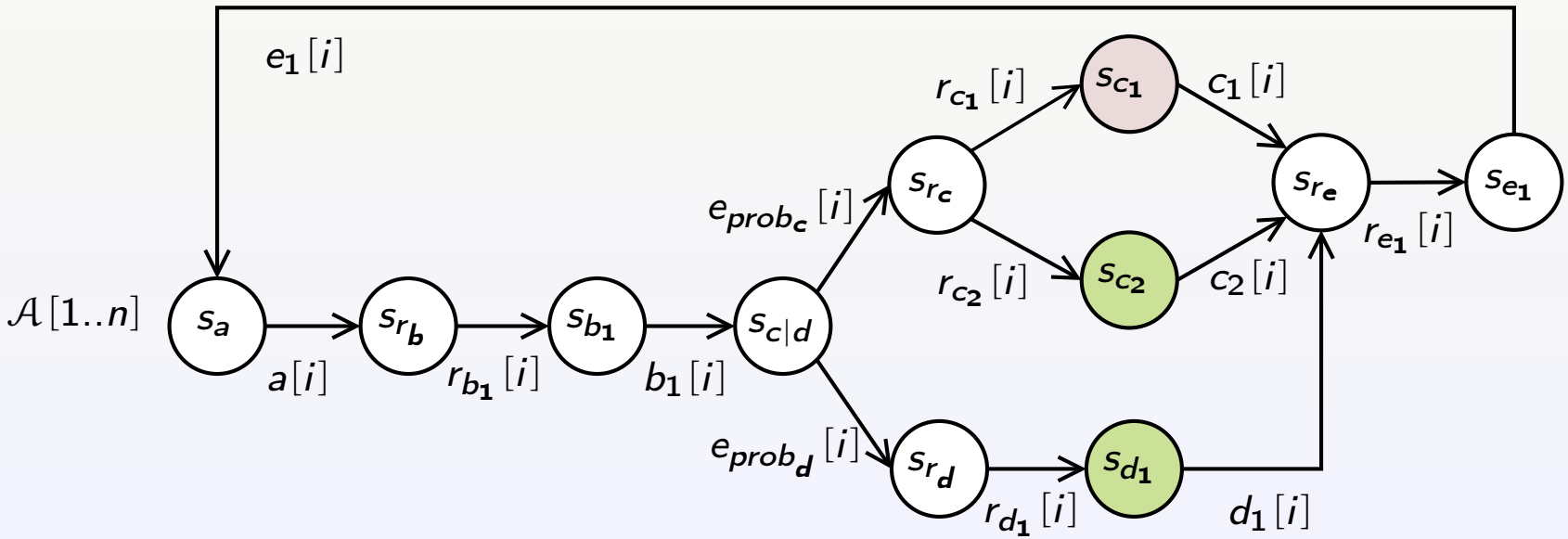
`qty_CNC1`	=	2;	`workCapacity_CNC1`	=	6.0;
`qty_Painting`	=	1;	`workCapacity_Painting`	=	10.0;

`requiredWork_C1_srr1_CNC1`	=	60.0;
`requiredWork_C1_srr2_Painting`	=	60.0;

Defining Event Rates II

Example: definition of rates of events $c_1[1..N]$

$$\begin{aligned}
\texttt{f_usedQty_CNC1} &= nb(\mathcal{A}[1..n], s_{c_1}); \\
\texttt{f_usedQty_Painting} &= nb(\mathcal{A}[1..n], s_{c_1}) + nb(\mathcal{A}[1..n], s_{c_2}) + \\
&\quad nb(\mathcal{A}[1..n], s_{d_1});
\end{aligned}$$



Defining Event Rates III

Example: definition of rates of events $c_1[1..N]$ (cont.)

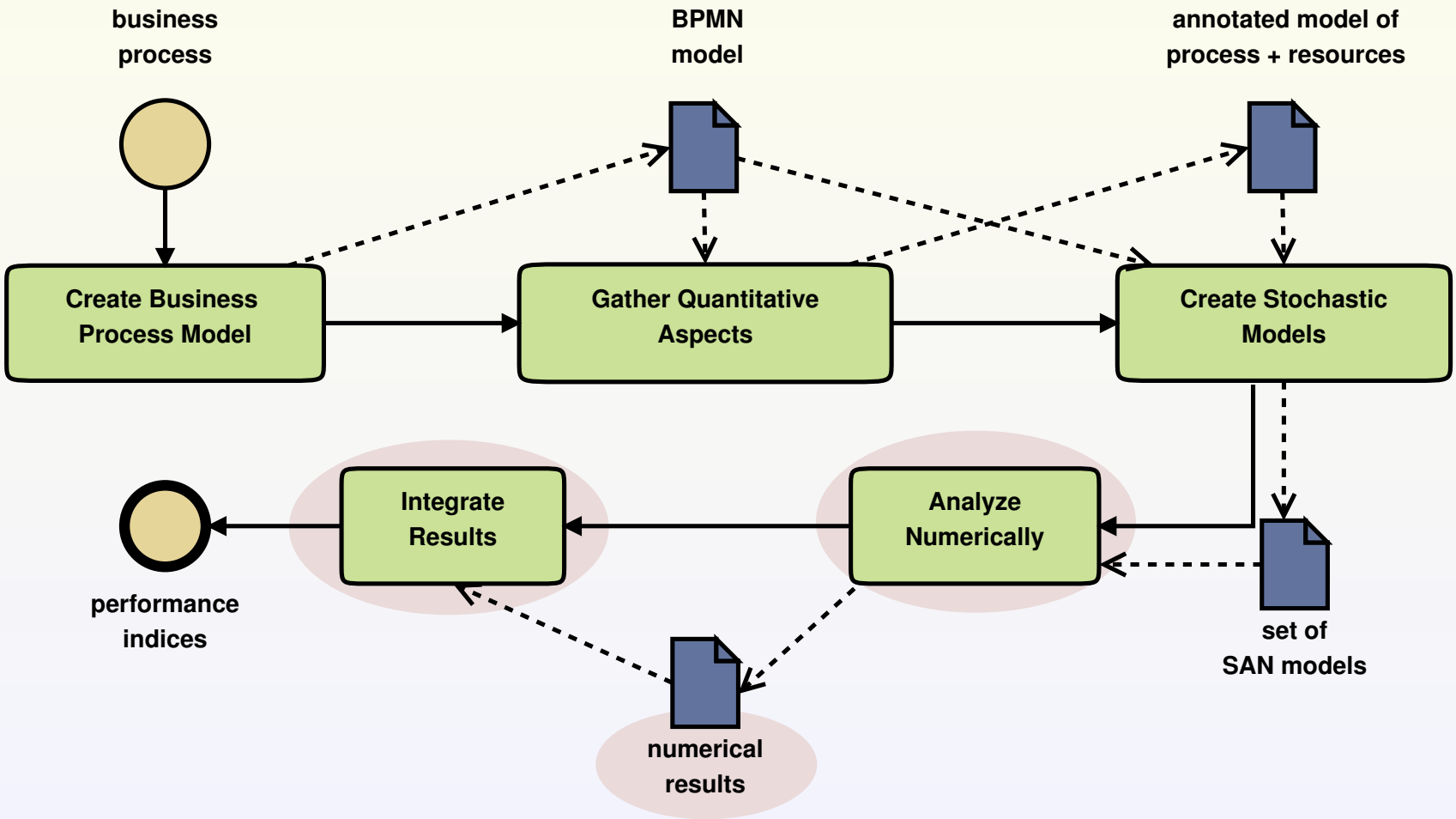
$$\texttt{f\_sharedWorkCapacity\_Painting} = \frac{\texttt{workCapacity\_Painting}}{\texttt{f\_usedQty\_Painting}};$$

$$\texttt{f\_rate\_C1\_srr1\_CNC1} = \frac{\texttt{workCapacity\_CNC1}}{\texttt{requiredWork\_C1\_srr1\_CNC1}};$$

$$\texttt{f\_rate\_C1\_srr2\_Painting} = \frac{\texttt{f\_sharedWorkCapacity\_Painting}}{\texttt{requiredWork\_C1\_srr2\_Painting}};$$

```
f_rate_C1 = min( f_rate_C1_srr1_CNC1,
                 f_rate_C1_srr2_PaintingM );
```

Part IV: Extraction of Performance Indices



Obtaining Indices from the Model Solution

Integration Functions of SAN

- Numerical functions over the state space of the system
- Integrated over the stationary probability distribution (π)

Examples of integration functions for performance evaluation

- Utilization of resource CNC2:
  $\texttt{f\_isInUse\_CNC2} = (\texttt{f\_usedQty\_CNC2} > 0)$
- Throughput of task b:
  $\texttt{f\_usefulRate\_B} = nb(\mathcal{A}[1..n], b_1) \times \texttt{f\_rate\_B1}$

Analysis of the Machine Shop Production Process

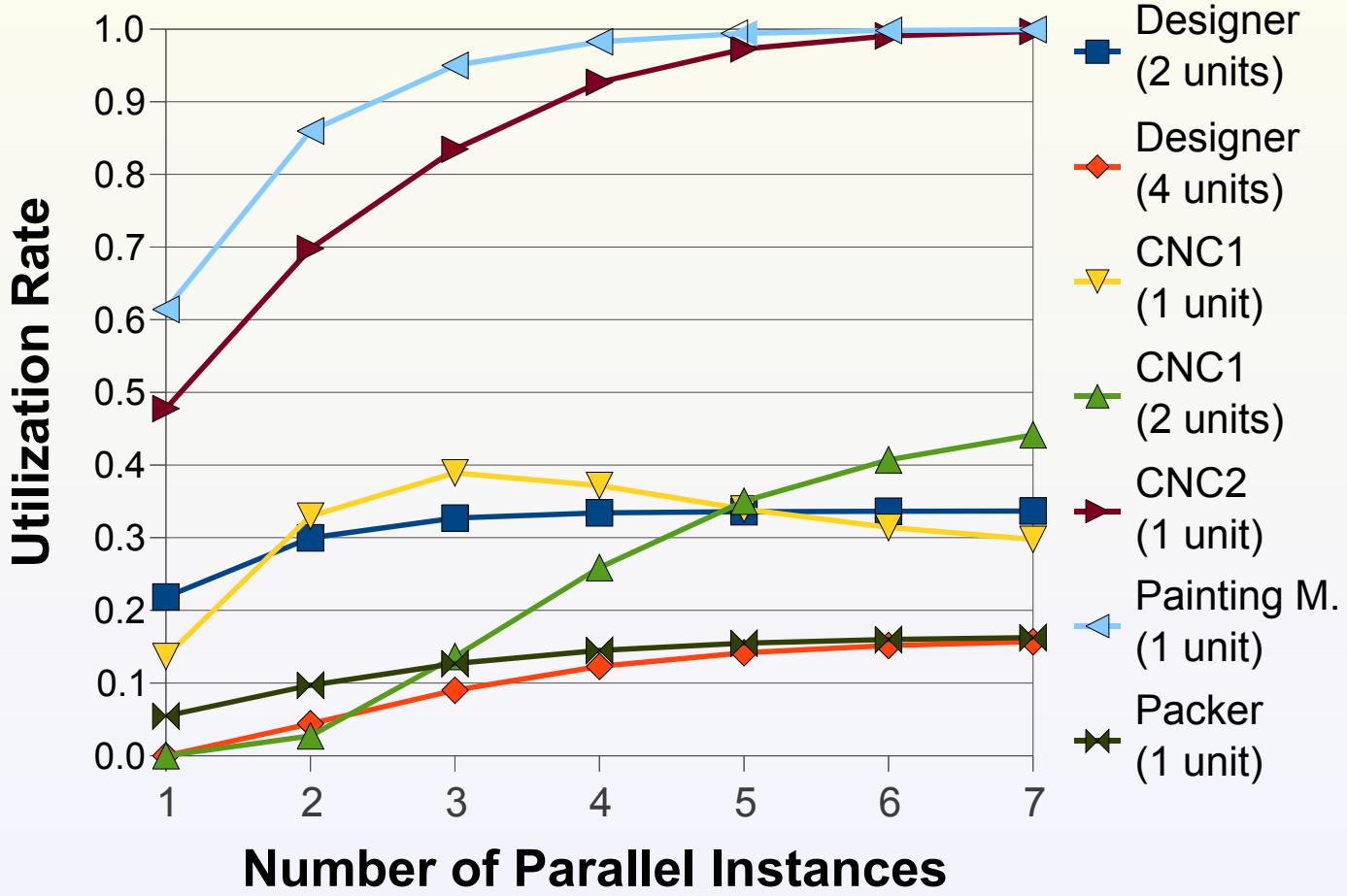
State Space size and computation time of the solution (using PEPS[1,2])

Parallel Instances	Size of Product State Space	Size of Reachable State Space	Computation Time
1	11	11	≈ 0 seconds
2	121	111	10^{-2} seconds
3	1,331	1,056	10^{-1} seconds
4	14,641	9,612	10^{1} seconds
5	161,051	84,456	10^{2} seconds
6	1,771,561	720,576	10^{3} seconds
7	19,487,171	5,995,296	10^{4} seconds

(1) **PEPS** – Performance Evaluation of Parallel Programs
`http://www-id.imag.fr/Logiciels/peps/`
(2) Using a Intel® Xeon® with 2.6 GHz and 32 GB of RAM

Some Performance Results

Utilization of resources in the Machine Shop process



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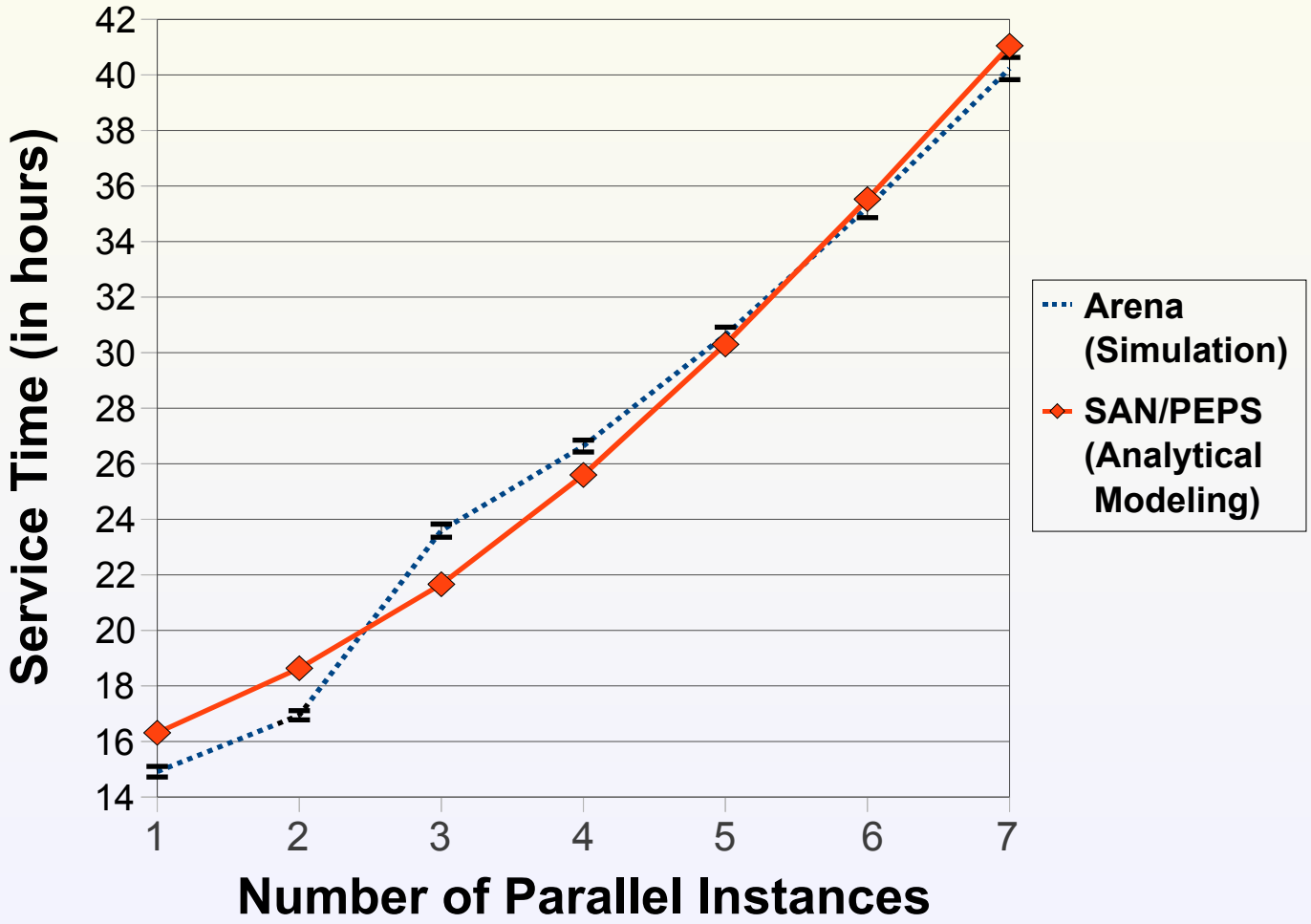
Validation of Our Approach

Service time of the Machine Shop production process



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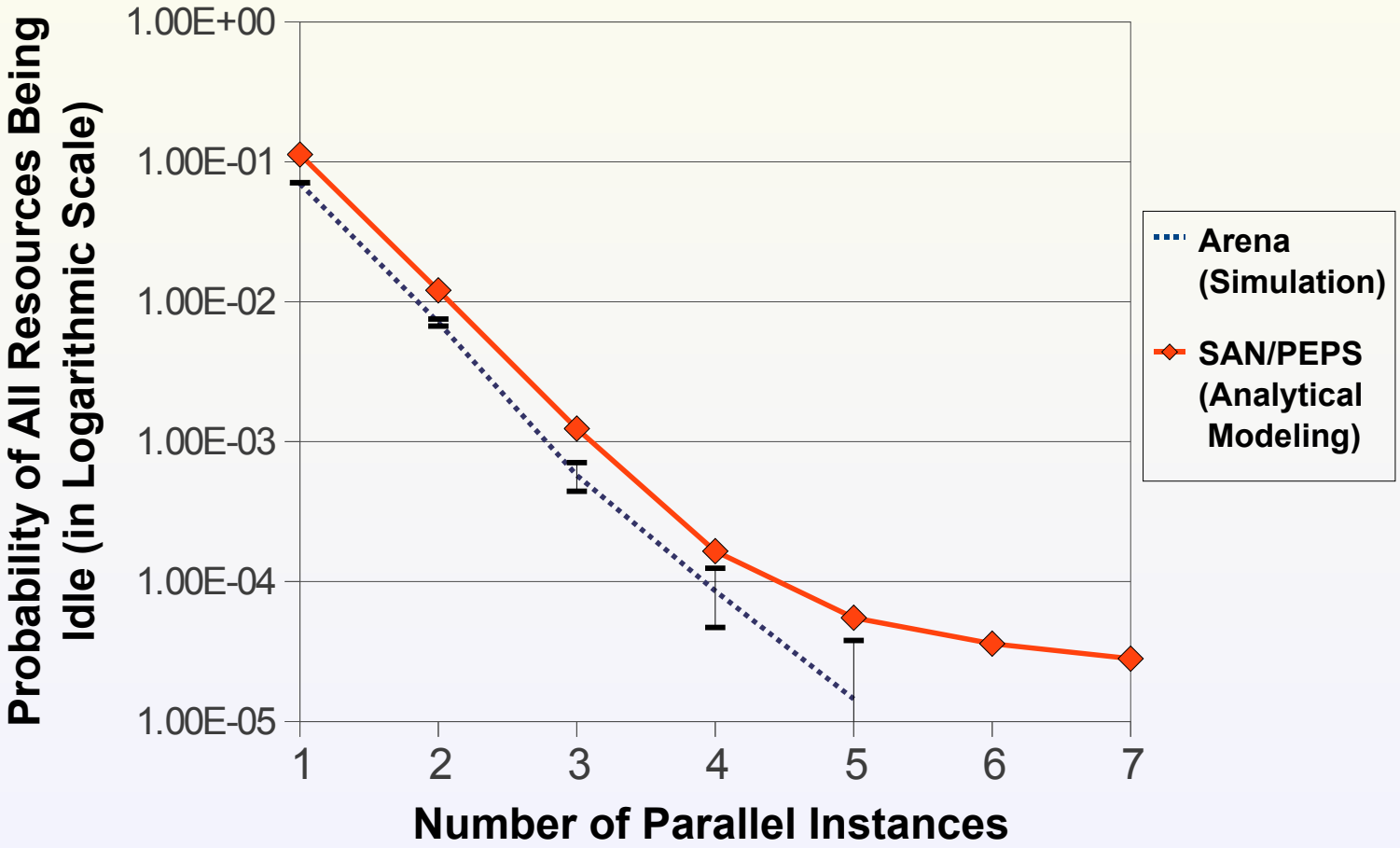
Simulation × Analytical Modeling

Probability of all resources being idle in the Machine Shop



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Automated Framework for Performance Evaluation of Resource-Aware Business Processes

Introduction of resource management in BP models

- Powerful (yet simple) notation to describe resource usage
- Quantify the performance degradation caused by increases on the workload

Automated conversion of BP models to SAN models

- Stochastic parameters inferred from the declaration of resources and requirements
- Ability to deal with large scale models

Publications I


K. R. Braghetto, J. E. Ferreira, J.-M. Vincent
"Performance Evaluation of Resource-Aware Business Processes Using Stochastic Automata Networks"
International Journal of Innovative Computing, Information and Control (IJICIC), special issue on Intelligent and Innovative Computing in Business Process Management (IICBPM), 2011.


K. R. Braghetto, J. E. Ferreira, J.-M. Vincent
"Performance Evaluation of Business Processes through a Formal Transformation to SAN"
8th European Performance Engineering Workshop (EPEW 2011)


K. R. Braghetto, J. E. Ferreira, J.-M. Vincent
"Performance Analysis Modeling Applied to Business Processes"
Symposium on Theory of Modeling & Simulation – DEVS Integrative M & S Symposium (DEVS'10)

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Publications II


K. R. Braghetto, J. E. Ferreira, J.-M. Vincent
"From Business Process Model and Notation to Stochastic Automata Network"
Research report (Reference Number: RT-MAC-2011-03), IME-USP, 2011.


K. R. Braghetto, J. E. Ferreira, J.-M. Vincent
"Comparison of Modeling Approaches to Business Process Performance Evaluation"
Research report (Reference Number: 7065), INRIA, 2009.

Research Perspectives

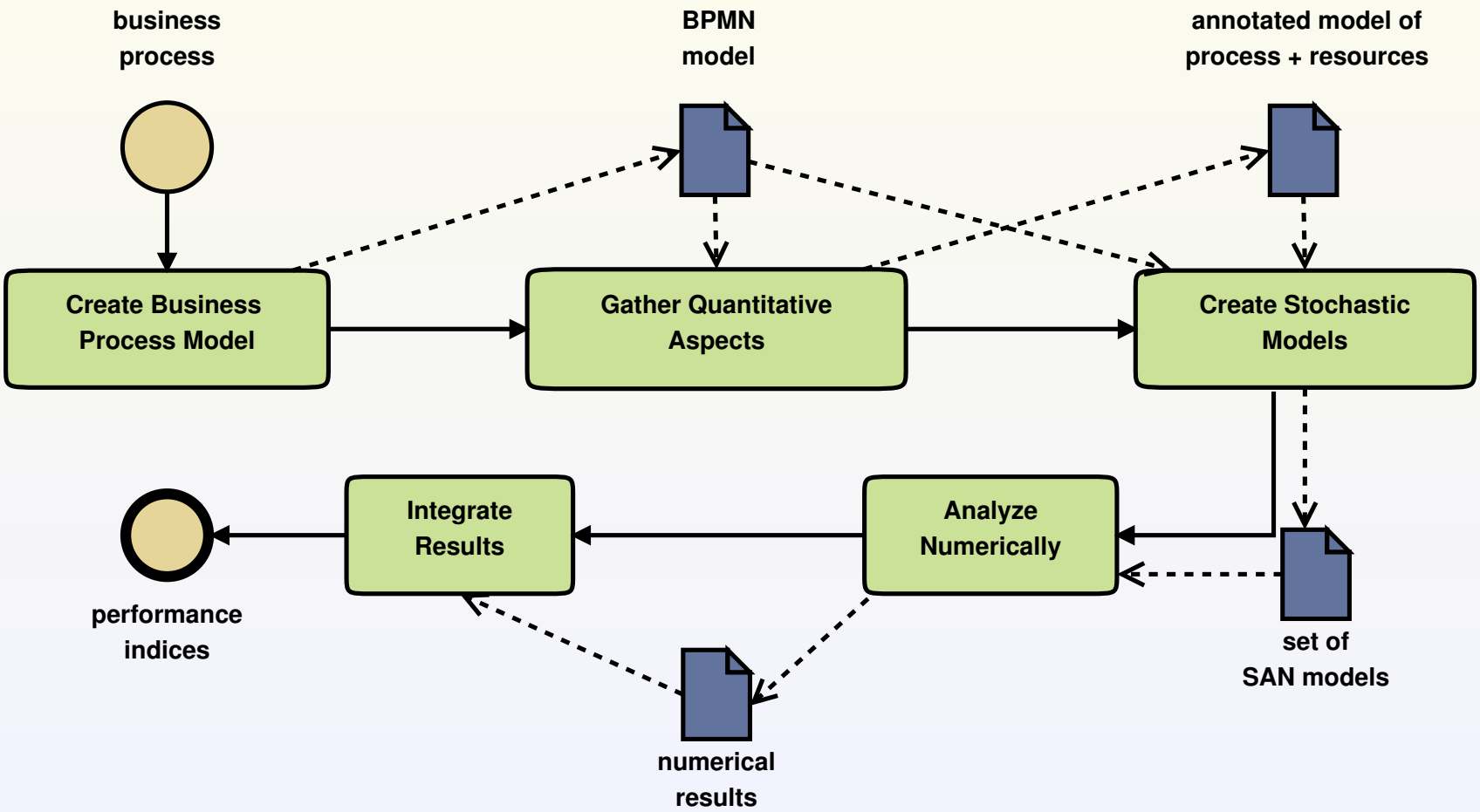
Short-term projects

- Extension of the conversion algorithm to cover a larger BPMN subclass
- Automatic decomposition of business process models

Long-term projects

- Mining of stochastic models from BP execution logs
- Application of the Mean Field theory in the performance analysis of business processes

I thank you for your attention



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