

A Formal Model for Representing Component Interfaces and Their Interaction

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Complexity in Software Engineering

- Construction of large-scale software projects is becoming increasingly difficult as architectures become more sophisticated.
- To combat complexity, there has been a natural, evolutionary trend from low-level constructs to higher-level abstractions in the software engineering process:
 - structured programming
 - object-oriented programming
 - aspect-oriented programming
 - architecture description languages
- In recent years, *component-based* software engineering has been proposed as a means of mitigating the complexities associated with construction of large software architectures.

Component Background

- Informal definitions of components are numerous. For example:
 - “An independently deliverable piece of functionality providing access to its services through interfaces.”

Alan W. Brown (2001) *An Overview of Components and Component-Based Development*.
 - “A software component is a unit of composition with contractually specified interfaces and explicit context dependencies only. A software component can be deployed independently and is subject to composition by third parties.”

Clemens Szyperski (2002) *Component Software : Beyond Object-Oriented Programming (second edition)*.
- Before an attempt can be made to automate analysis of component systems, formal definitions of *component* must be proposed. Such definitions are beginning to appear in the literature.
- *Component compatibility* is required for reusability and substitutibility in software development and maintenance.

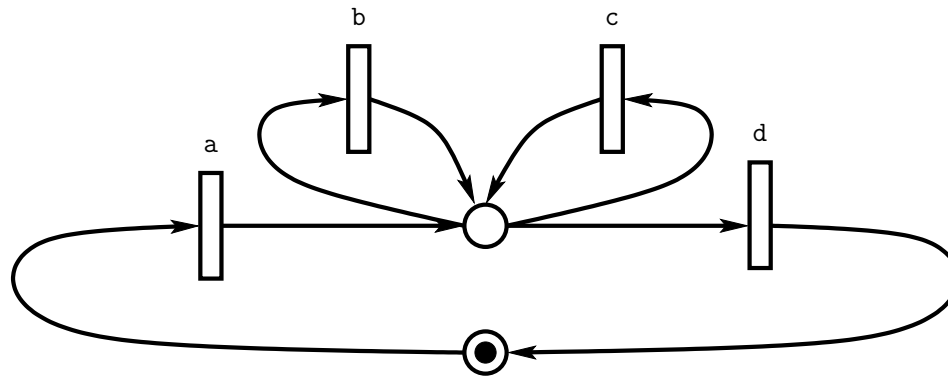
Petri Net Interface Model

- It is assumed that internal behavioural semantics of components are unimportant and the behaviour can be described as a set of service sequences (or a set of sequences of interface operations).
- This behaviour is represented by a (cyclic) labelled Petri net:

$$\mathcal{M}_i = (P_i, T_i, A_i, S_i, \ell_i, m_i), \quad \ell_i : T_i \rightarrow S_i, \quad m_i : P_i \rightarrow \{0, 1, \dots\}.$$

Different services are represented by different labels from the set S_i .

- Component interactions occur between requester interfaces (*r-interfaces*) and provider interfaces (*p-interfaces*). The same component can have several r-interfaces and several p-interfaces.



Petri Net Model — Interface Languages

- The behaviour of an interface \mathcal{M}_i is described by a protocol or language which is the set of all (initial) firing sequences, $\mathcal{F}(\mathcal{M}_i)$.
- A single firing sequence σ from this set is:

$$\sigma = t_{i_1} t_{i_2} \dots t_{i_k} \Leftrightarrow (\forall 0 < j \leq k : t_{i_j} \in E(m_{i_{j-1}}) \wedge m_{i_{j-1}} \xrightarrow{t_{i_j}} m_{i_j}) \wedge m_{i_0} = m_i,$$

where $E(m)$ is the set of transitions enabled by the marking m .

- The language of \mathcal{M}_i , denoted by $\mathcal{L}(\mathcal{M}_i)$, is defined as:

$$\mathcal{L}(\mathcal{M}_i) = \{ \ell(\sigma) \mid \sigma \in \mathcal{F}(\mathcal{M}_i) \wedge \ell(\sigma) \text{ is a complete sequence of operations} \},$$

where $\ell(t_{i_1} \dots t_{i_k}) = \ell(t_{i_1}) \dots \ell(t_{i_k})$ and a *complete sequence of operations* represents a session of requester/provider interactions (*i.e.*, a cycle of an interface model).

Interface Composition

An r-interface $\mathcal{M}_i = (P_i, T_i, A_i, S_i, \ell_i, m_i)$ composed with a p-interface $\mathcal{M}_j = (P_j, T_j, A_j, S_j, \ell_j, m_j)$ creates a new net $\mathcal{M}_{ij} = (P_{ij}, T_{ij}, A_{ij}, S_i, \ell_{ij}, m_{ij})$, provided that $S_i \subseteq S_j$ and where:

$$P_{ij} = P_i \cup P_j \cup \{ p_{t_i} : t_i \in \hat{T}_i \} \cup \{ p'_{t_j}, p''_{t_j} : t_j \in \hat{T}_j \},$$

$$\text{where } \hat{T}_i = \{ t \in T_i : \ell_i(t) \neq \varepsilon \}, \quad \hat{T}_j = \{ t \in T_j : \ell_j(t) \neq \varepsilon \},$$

$$T_{ij} = T_i \cup T_j - \hat{T}_i \cup \{ t'_i, t''_i : t_i \in \hat{T}_i \},$$

$$A_{ij} = A_i \cup A_j - P_i \times \hat{T}_i - \hat{T}_i \times P_i \cup$$

$$\{ (p_i, t'_i), (t'_i, p_{t_i}), (p_{t_i}, t''_i), (t''_i, p_k), (t'_i, p'_{t_j}), (p'_{t_j}, t_j), (t_j, p''_{t_j}), (p''_{t_j}, t''_i) :$$

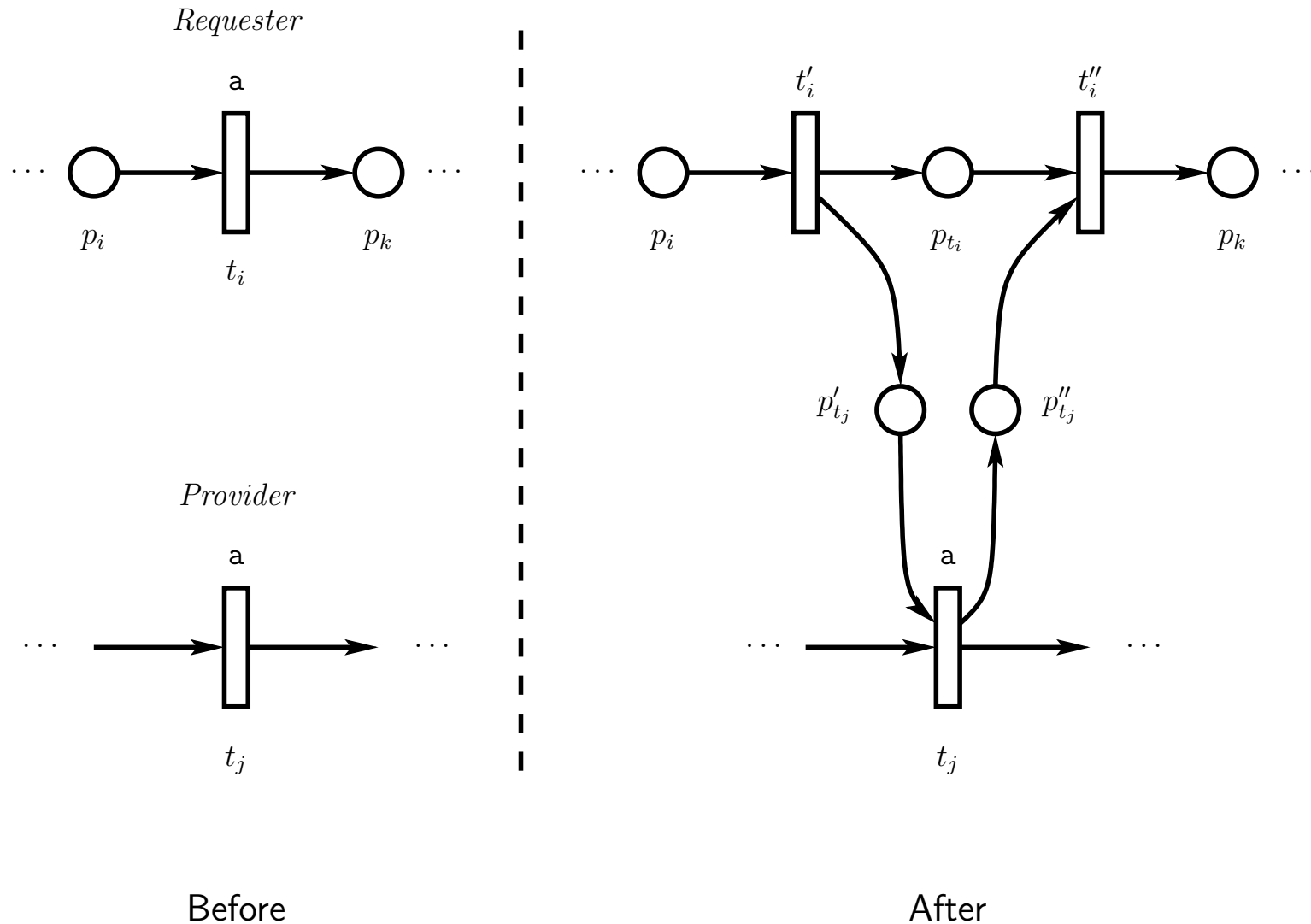
$$t_i \in \hat{T}_i \wedge t_j \in \hat{T}_j \wedge \ell_i(t_i) = \ell_j(t_j) \wedge (p_i, t_i) \in A_i \wedge (t_i, p_k) \in A_i \},$$

$$\forall t \in T_{ij} : \ell_{ij}(t) = \begin{cases} \ell_i(t), & \text{if } t \in T_i, \\ \ell_j(t), & \text{if } t \in T_j, \\ \varepsilon, & \text{otherwise;} \end{cases}$$

$$\forall p \in P_{ij} : m_{ij}(p) = \begin{cases} m_i(p), & \text{if } p \in P_i, \\ m_j(p), & \text{if } p \in P_j, \\ 0, & \text{otherwise.} \end{cases}$$

Interface Composition (cont'd)

A composition, for a single interface operation, can be illustrated as follows:



Component Compatibility

- In the composed net, all (nontrivially) labelled transitions are shared by both interfaces.
- Any string generated by the resulting composition can also be generated by each interface:

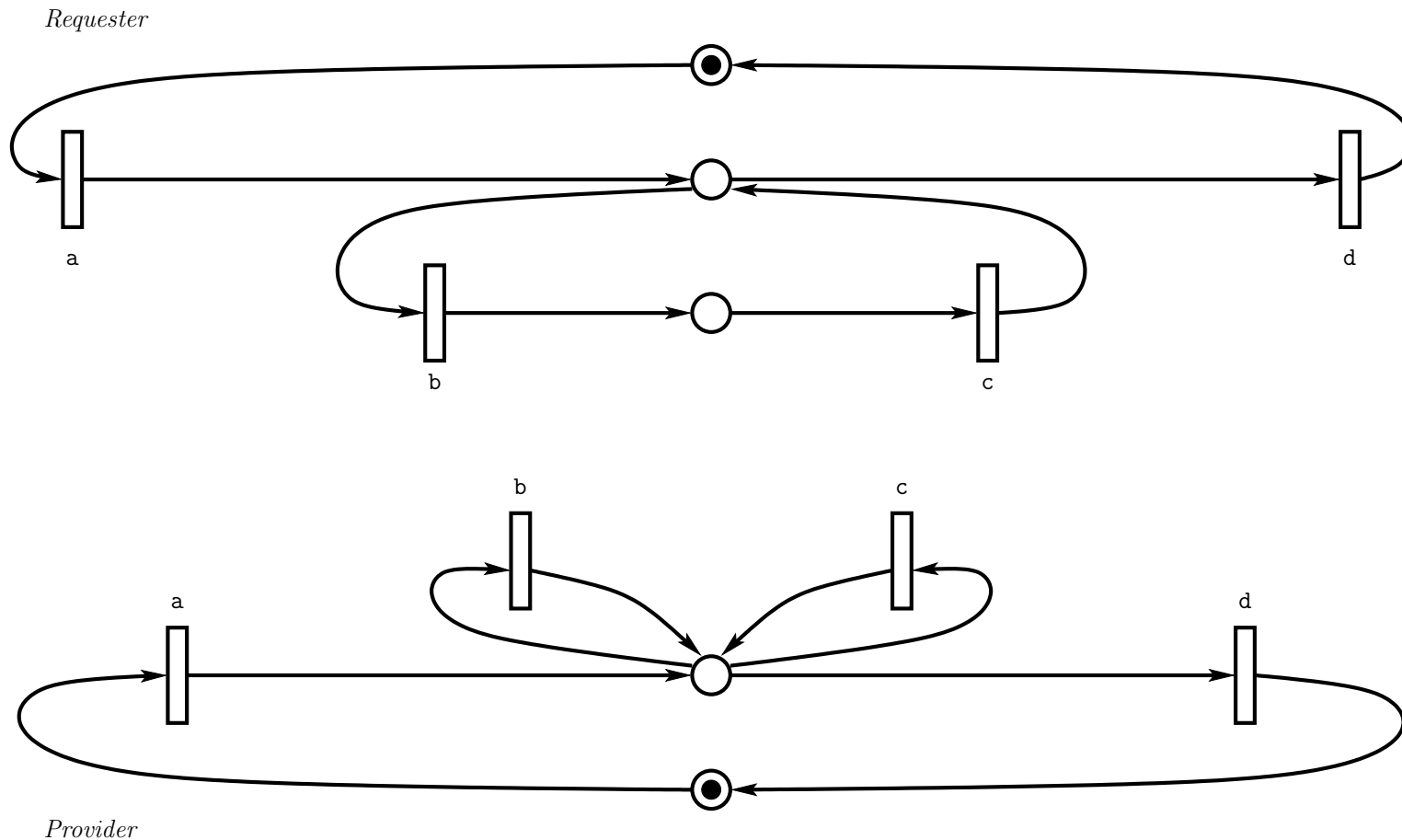
The language of the composition of two interfaces with the same alphabet S , an r-interface \mathcal{M}_i and a p-interface \mathcal{M}_j , $\mathcal{M}_i \triangleright \mathcal{M}_j$, is the intersection of $\mathcal{L}(\mathcal{M}_i)$ and $\mathcal{L}(\mathcal{M}_j)$, $\mathcal{L}(\mathcal{M}_i \triangleright \mathcal{M}_j) = \mathcal{L}(\mathcal{M}_i) \cap \mathcal{L}(\mathcal{M}_j)$.

- The compatibility of two components can be checked by detecting deadlocks in the composed net:

Two interfaces with the same alphabet S , an r-interface \mathcal{M}_i and a p-interface \mathcal{M}_j are incompatible iff the composition $\mathcal{M}_{ij} = \mathcal{M}_i \triangleright \mathcal{M}_j$ contains a deadlock.

Example 1

Consider database client and server components. The server (provider) supports an *open* operation (a), followed by any number of *read/write* operations in any order (b|c)* followed by a *close* operation (d). The interface language of the client (requester) is a subset of this language.

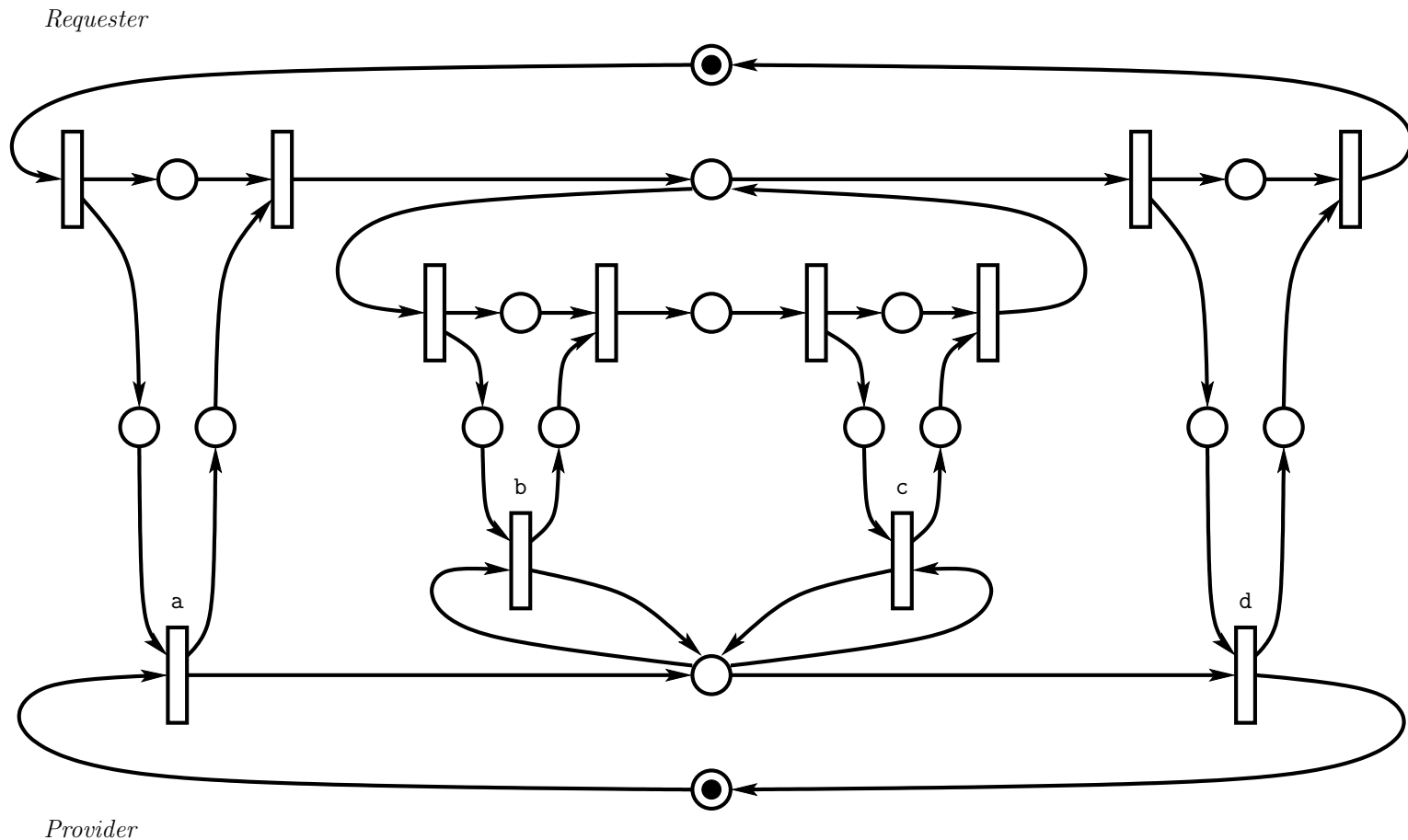


Example 1 (cont'd)

Provider language $\mathcal{L}_P = (a(b|c)^*d)^*$; requester language $\mathcal{L}_R = (a(bc)^*d)^*$

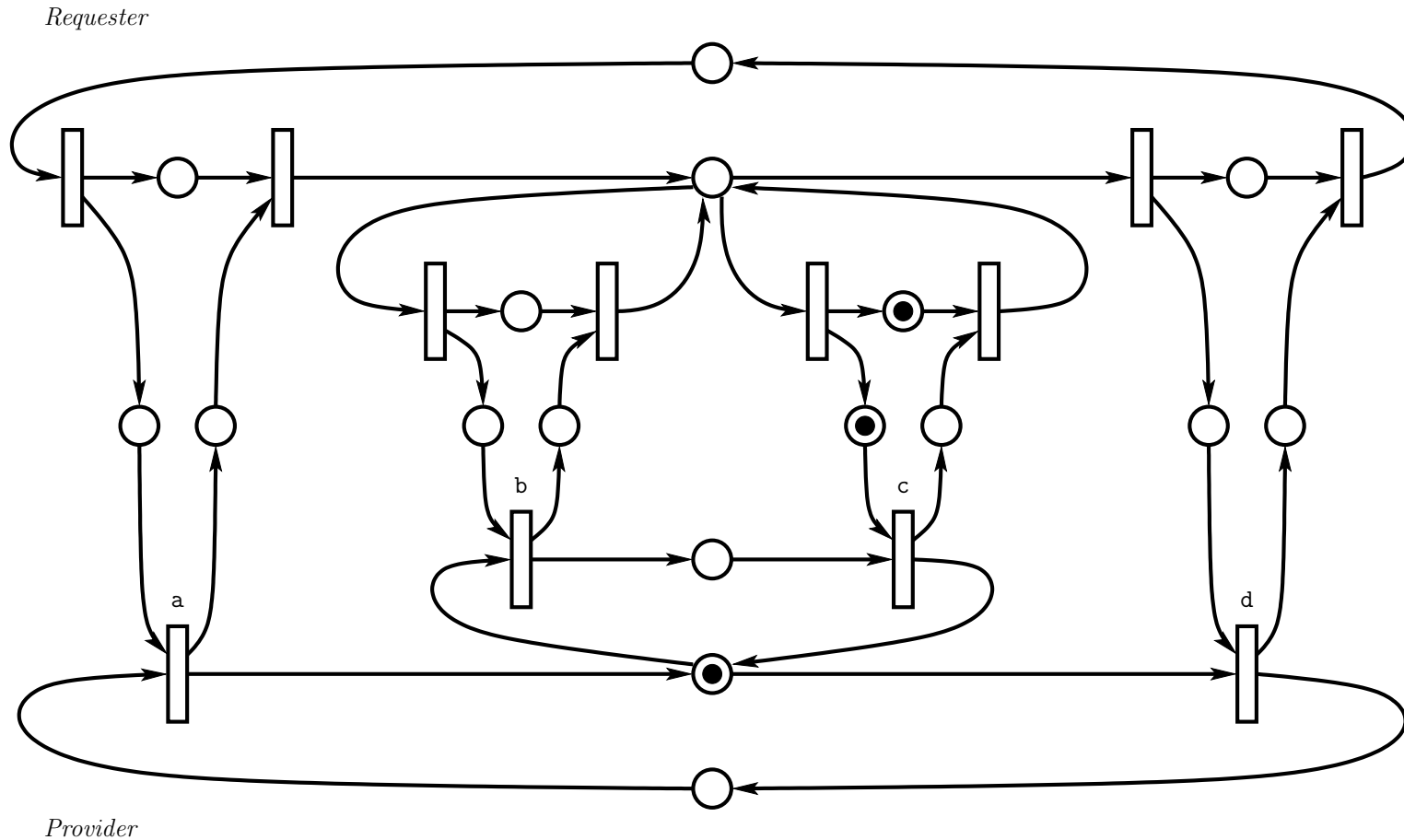
Note: $\mathcal{L}_R \subseteq \mathcal{L}_P$, so $\mathcal{L}_R \cap \mathcal{L}_P = \mathcal{L}_R$.

$\mathcal{M}_{ij} = \mathcal{M}_i \triangleright \mathcal{M}_j$ is deadlock-free $\Rightarrow \mathcal{M}_i$ is compatible with \mathcal{M}_j .



Example 1 (cont'd)

Swapping the provider and requester in the previous example, so $\mathcal{L}_P = (a(bc)^*d)^*$ and $\mathcal{L}_R = (a(b|c)^*d)^*$, results in composition that exhibits a deadlock as shown below:

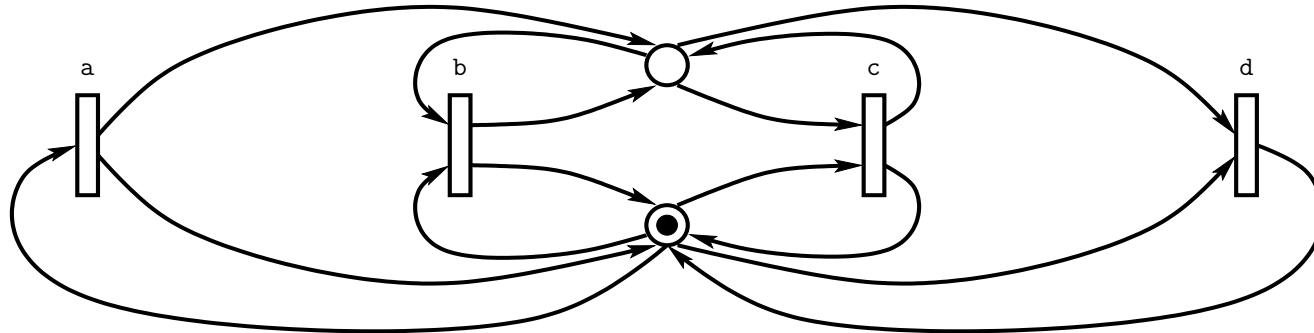
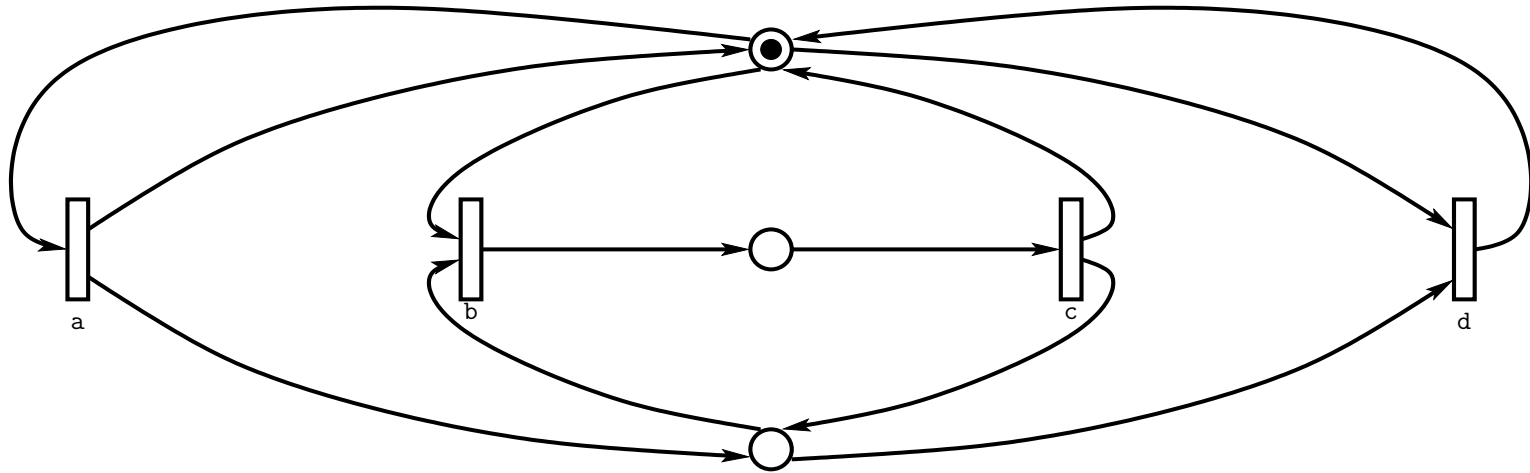


$\mathcal{L}_R \not\subseteq \mathcal{L}_P$, \mathcal{M}_i is incompatible with \mathcal{M}_j .

Example 2

Context free languages (e.g. nested transactions on a database).
Before composition:

Requester

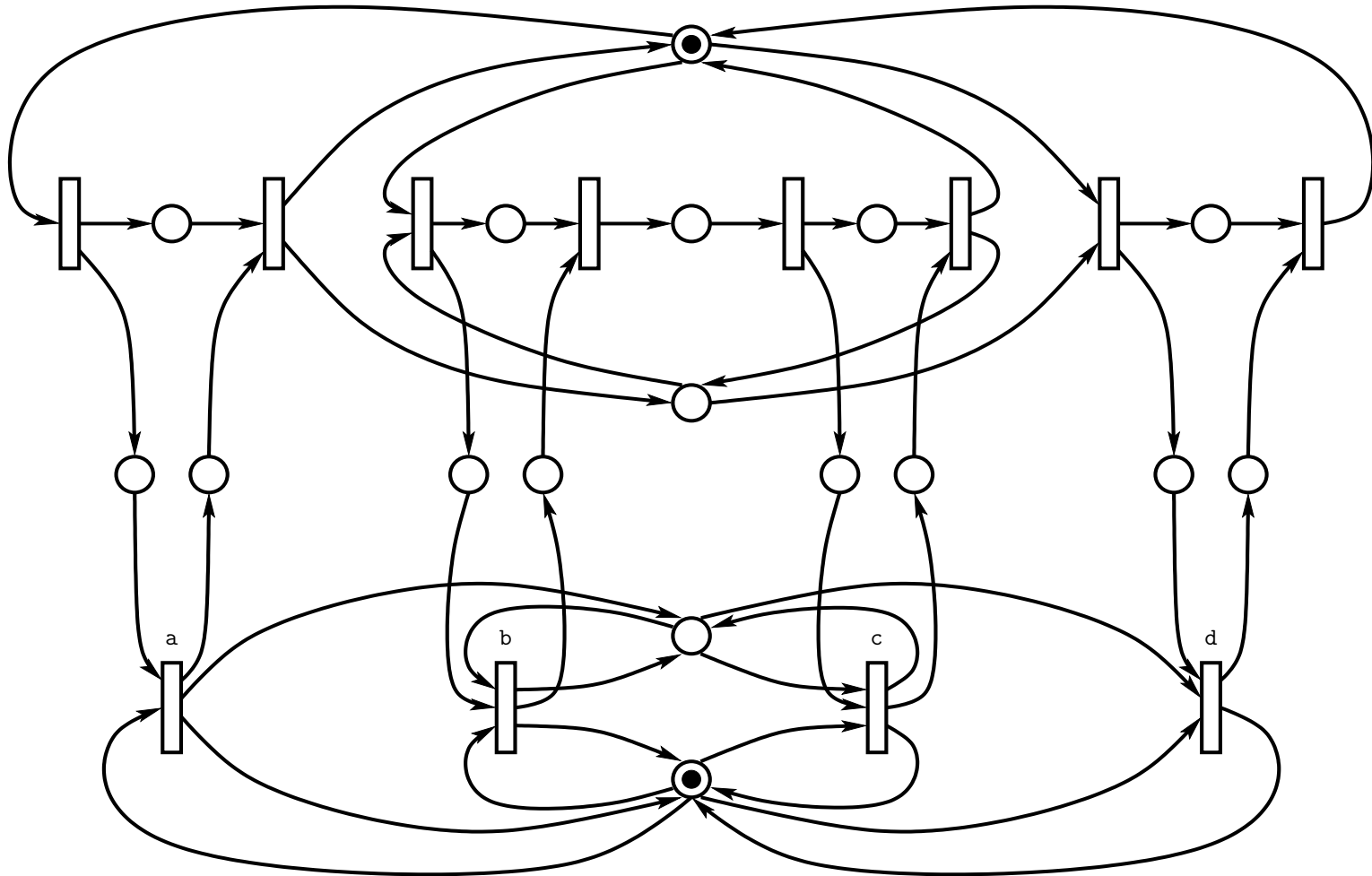


Provider

Example 2 (cont'd)

Context free languages (e.g. nested transactions on a database).
After composition:

Requester



Provider

Conclusions and Future work

- Static and dynamic component aspects must be understood in order to determine compatibility.
- Compatibility can be checked by representing the interface behaviours as Petri nets and then composing them.
 - If the resulting net exhibits deadlock, then the components are not compatible.
 - Deadlock detection – structural techniques can be applied given the presence of cyclic subnets.
- Hierarchical representations of component interfaces in complex software architectures follows the same approach.
- Dynamic reconfiguration/collaboration between components may be possible. (Self assembling software?)