APPLYING BCMP MULTI-CLASS QUEUEING NETWORKS FOR THE PERFORMANCE EVALUATION OF HIERARCHICAL AND MODULAR SOFTWARE SYSTEMS

Simonetta Balsamo Gian-Luca Dei Rossi Andrea Marin

Dipartimento di Informatica
Università Ca' Foscari, Venezia

ESM'2010 Conference, October 25-27 2010

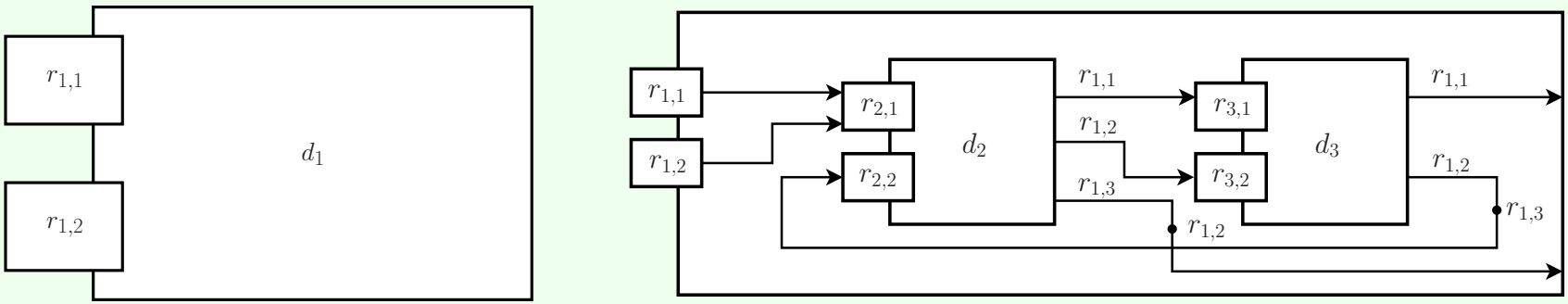
Outline

- Software Modularity and Performance Evaluation
- BCMP Queueing Networks
- An approach to modular and hierarchical software design
- The unfolding algorithm
- Applications and examples
- Conclusion

Modular and Hierarchical Software Design

- Performance analysis of modular and hierarchical systems always an important topic in research (see Smith (1990)).
- Software system: interaction between black-box components, made of other black-box components ...

An example of a black-box component



Main problem

Defining efficient algorithms to derive performance indexes.

BCMP Networks

BCMP Networks (Baskett et al. (1975)) are one of the most useful models for performance evaluation.

- A set of queueing centers and a (possibly infinite) set of customers.
- Classes, that determine:
  - routing probabilities;
  - service time distributions.
- Each class belongs to a chain
  - *open* (external arrivals) or *closed*.
- Class switching only within the same chain.
- Queueing station of one of the following types:
  1. FCFS Queueing discipline. Exponential and class-independent service time distribution,
  2. PS Queueing discipline,
  3. The station has infinite servers (*Delay Station*),
  4. LCFSPR service discipline.

With coxian service time distribution

The BCMP Theorem

BCMP Theorem (salient results)

Let us consider a multiple-class and multiple-chain QN, open, closed or mixed, whose queueing stations are of type 1, 2, 3 or 4. If the underlying stochastic process is ergodic, then:

$$\pi(\mathbf{n}) = \frac{1}{G} \prod_{i=1}^{M} g_i(n_i),$$

where

- $\mathbf{n} = (n_1, \ldots, n_M)$ is the state of the network, n_i is the state of station S_i;
- π is the steady-state distribution of the QN;
- $g_i(n_i)$ is the steady-state distribution of station S_i considered in isolation;
- G is a normalising constant.

BCMP pro and cons

- BCMP Networks are widely used. Various solution algorithms.
  - for *open* networks, $G = 1$.
  - for *closed* or *mixed* network, algorithms to compute G or directly derive the average performance indices.
- BCMP Networks are inherently *flat*.
  - no modular and/or hierarchical design.

We propose an algorithm to compute a BCMP from an modular and hierarchical high-level model.

The design framework

A framework for the specification of hardware and software architectures.

- A set of interacting components $d_1, d_2, \ldots, d_{\ell_1}$. Each component can be
  - A BCMP queueing station
  - A sub-model consisting of components $d_{(i)1}, \ldots, d_{(i)\ell_2}$.
- Components interact as stations of an open multiple-class and multiple-chain QN.
- Sub-models as black boxes
  - access points with some labels, i.e., input and output classes.

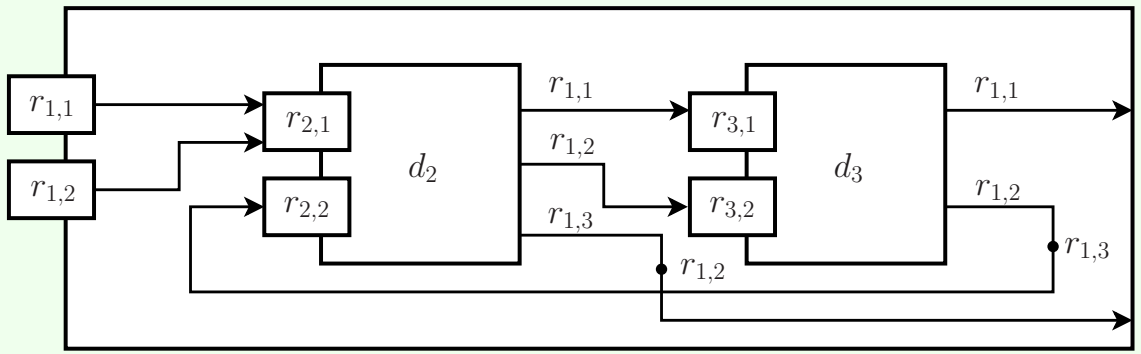
We require that

- the set of input classes and the set of output classes must be equal,
- the model must be *well formed*.

More on the design framework

- A higher level class could be connected to any lower level class.
- Multiple classes of the higher level submodel could be connected to the same lower level class.
- The same component could be reused in different submodels.

An example of design of a CMS module



Class connections: $A_{d_i,d_j} : \mathcal{R}_i \rightarrow \mathcal{R}_j$

How to keep routing information in case of component or class reuse?

The Algorithm

Algorithm UnfoldComponents

Input: routing matrix $\mathbf{P}_d$ of component d, component counter array Dc, functions $A_{i,j}$
Output: unfolded routing matrix $\mathbf{P'}_d$ of component d
if *d is a station* **then**
    foreach *class r of d* **do**
        insert in $\mathbf{P'}$ rows and a columns for EI_d, r and EO_d, r of $\mathbf{P}$
    end
else
    foreach $d_i | d \succ d_i$ **do**
        $Dc_i \leftarrow Dc_i + 1$
        Let Rc_i be a class counter array
        foreach *class r_k of d_i as named in d* **do**
            $r_{i,j} \leftarrow \mathtt{A}_{d,d_i}(r_k)$
            $Rc_{i,j} \leftarrow Rc_{i,j} + 1$
            if $Rc_{i,j} > \max Rc_i$ **then**
                $\mathbf{U} = \mathtt{UnfoldComponents}(\mathbf{P}_{d_i})$
                rename each class $r_{i,j}$ of d_i in $\mathbf{U}$ as $r_{i,j,Dc_i,Rc_{i,j}}$
                insert in $\mathbf{P'}$ rows and columns of $\mathbf{U}$
            end
            replace column $EI_{d_i}, r_{i,j,Dc_i,Rc_{i,j}}$ in $\mathbf{P'}$ with column d_i, r_k of $\mathbf{P}$
            replace row $EO_{d_i}, r_{i,j,Dc_i,Rc_{i,j}}$ in $\mathbf{P'}$ with row d_i, r_k of $\mathbf{P}$
        end
    end
end
return P'

Some notes on the algorithm

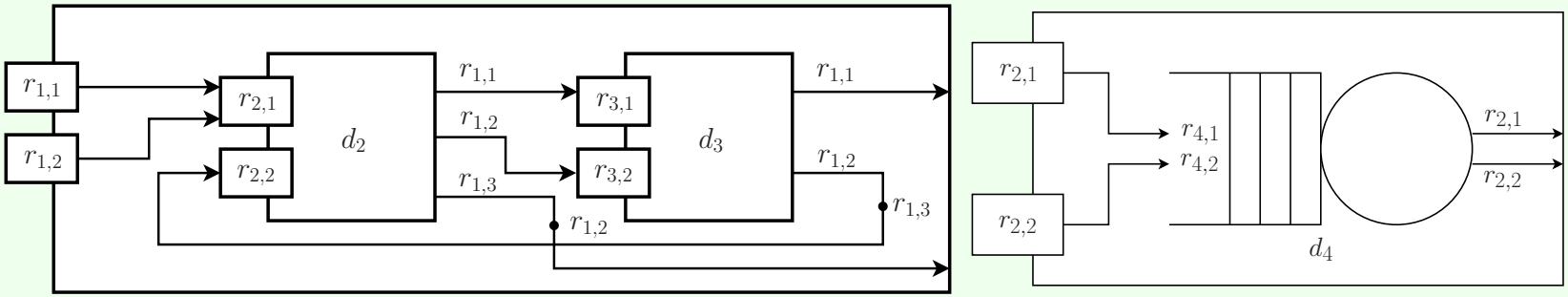
- Recursive and top-down.
- It adds classes whenever it is needed in order to not loose customer routing information.
- Base cases: BCMP queueing stations.
- Output: multiple-class, multiple-chain BCMP network.
- Computational complexity $\mathcal{O}(rd^n)$ if, on average:
  - every component has the same number of sub-components d,
  - every component has the same number of classes r,
  - the depth of the model is n.

A small example

Database-indexed file archive for a CMS.

- A class of customer for read operations.
- A class of customers for write operations.

The CMS file archive module and the DB Module



How many classes should station d_4 have at the end of the algorithm run?

A small example (2)

d_4 should have *at least* 4 classes.

- The algorithm doubles the number of classes for d_2.
- The classes of d_2 translates directly in classes of d_4.
- We cannot know if d_4 or d_2 are used by other components.
- More complex model topology may lead to a rapid increase of the number of classes.

Conclusion and future works

- A modeling technique for hierarchical systems.
- An algorithm that transforms such models in a multi-class and multi-chain BCMP.
- Main advantages:
  - a modular and hierarchical modelling technique,
  - an efficient and exact analysis method.
- More expressive formalisms, like LQNs in Woodside et al. (1995) may require approximate algorithms.
- Future works:
  - extension of the tractable class of models,
  - integration of the framework with web mining and log analysis.

Any question?

References

Balsamo S. and Marin A., 2007. *Queueing Networks in Formal methods for performance evaluation*, M. Bernardo and J. Hillston (Eds), LNCS, Springer, chap. 2. 34–82.

Baskett F.; Chandy K.M.; Muntz R.R.; and Palacios F.G., 1975. *Open, Closed, and Mixed Networks of Queues with Different Classes of Customers*. *J ACM*, 22, no. 2, 248–260.

Smith C.U., 1990. *Performance Engineering of Software Systems*. Addison-Wesley.

Woodside C.; Neilson J.; Petriu S.; and Mjumdar S., 1995. *The Stochastic rendezvous network model for performance of synchronous client-server-like distributed software*. *IEEE Transaction on Computer*, 44, 20–34.