MAY SIMULATION LANGUAGE TUTORIAL

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1. Heirarchical Model Development

1.1 Model Development

A model is a simplified representation of a complex physical system. A model is constructed to gain a better understanding of a system by predicting its performance under a variety of different operating conditions. Most modelers adopt a top-down, *iterative* approach to system modeling. Initially, the modeler constructs a very simple model of the system to answer fundamental questions about basic alternatives. The initial model contains many simplifications either because details of the system remain undecided, or their inclusion in the model is considered unnecessary. To be useful, this model must be able to evaluate a large number of alternatives quickly and inexpensively. As decisions are made about the system organization, the high-level structure of the model stabilizes. However, each system componenet still has a very simple representation. In order to obtain more accurate results, the modeler refines the model iteratively. An iteration introduces additional complexity in the model by increasing the amount of detail in the representation of some components. During the implementation of the system, design estimates can often be replaced by measured values. The model is then re-evaluated to examine the impact of inaccuracies in the initial predictions. This process is continued until a complete model with the desired complexity is obtained or the system has been constructed. Once the system becomes operational, the model does not become useless. The model may be used to tune the system to its environment and to predict the impact of proposed changes in the system and its workload.

Due to the high resource requirements of constructing a model, sub-models may be developed concurrently by a group of modelers. Frequently, the same sub-model may be used to represent a number of components in various physical systems. As an example, an *active_server* may be used to model the CPU of a computer system or the cashier at the check-out counter of a grocery store.

To illustrate the ideas presented in this section, we consider the construction of a simulation model of a supermarket. The purpose of the model is to estimate the average time taken by a customer to pass through the check-out counter as a function of the number of items he has purchased. In our model of the supermarket, a customer arrives at the check-out counter with an arbitrary number of items, waits in a queue associated with a cashier, pays the appropriate amount and leaves the store. We have chosen this everyday example because it captures many of the complex scheduling and capacity planning issues involved in the design of computer systems. To illustrate this complexity, consider some fairly typical behavior patterns: a customer waiting in a queue notices another queue being serviced faster, and decides to join the faster queue (customer *reneging*); the machine being used by a specific cashier may malfunction temporarily (server *failure*), or the cashier may close his queue if it becomes too long (finite *queue capacity*); a customer may desire to be serviced at a specific counter, which is not necessarily the one with the shortest queue (customer *affinity* for one of many servers); a customer may request priority service (different *service disciplines*), etc. Rather than attempting to capture the entire complexity of the system, the modeler may initially choose a very simple model -- for instance, a simple FCFS server. In this model, a single server services its queue in a FCFS manner. When a customer needs service, he joins the queue, and waits until he has received the required service. The arrival of customers is modelled by a *source* entity, and a *sink* entity models their departure from the system. Since the FCFS server is a frequently used model, it may be selected from a library of models maintained by the modeler. The parameters of the general FCFS server are assigned appropriate values and the model executed. Based on the results of executing his initial model, the modeler may refine the model as follows: two types of service-centers are introduced -- *express* lanes to service customers with very small service requirements, and *general* lanes for the remaining customers. The refined model consists of two sub-models, each of which is a FCFS server. The arrival-rate of customers for each FCFS server should be adjusted to match the overall arrival-rate in the earlier model. The two sub-models may be developed concurrently by different modelers. The sub-model for the *general* lanes can be refined independently of the other sub-model by replacing the FCFS server by a collection of FCFS servers which are fed from a common *source*. Complex system behavior like customer *reneging*, server *failures*, finite *queue capacity*, and customer *affinity* may be introduced iteratively in the model. The sub-model for the *express* lanes may be refined independently to experiment with other service disciplines, like priority service based on number of items purchased by a customer (*shortest job next*).

There are four important aspects to the modeling process described above:

1. Reusability: A sub-model can be used to represent a variety of different components.

2. Evolution: In general, a model evolves over time from simple to complex. The representation of a system component may change depending on the amount of information available and on the perceived effect of the component on the performance parameter being measured. This implies that the system components may be modeled at increasing levels of complexity during the evolution of the model.

3. Cooperation: A group of modelers cooperate in the model development process.

4. Multiple Copies: Several versions of a model may exist simultaneously. Each version may include details needed to answer a particular question. It follows that different versions of a model may incorporate different levels of complexity in the representation of a given component.

The system described in this paper attempts to capture each of the above aspects of the modelling process. Reusability has been an important criterion in the design of a number of modeling packages and led to the adoption of a tool-based approach to modeling. In this approach, the system provides a library of modelling tools called *entities*. Each *entity* in the library models a specific component. In addition, the library may also contain entities for statistics collection and report generation. This tool-based approach effectively captures the philosophy of top-down decomposition of a model into simpler sub-models. If each component in the system being modelled can be represented by an entity from the model library, the model may be constructed conveniently by selecting the appropriate entities from the library. However, the general tool-based approach does not provide any help in the evolution of a sub-model to introduce more complex behavior patterns. Typically, the model library contains a *single* entity to represent a group of physical components. This forces the modeler to design his model at the precise level of complexity that has been built into each entity in the library. As a consequence, if the library entity is too complex, the modeler is forced to deal with a large number of parameters that he may be unable to specify, or if it is too simple, use a simpler model than he needs. This has been a classic shortcoming of most library-based systems. We introduce the concept of hierarchical reusability as a solution to some of these problems. The next chapter presents a series of examples which illustrate how hierarchies may be used to develop models of simple computing systems. The following chapters describe three hierarchies for modeling: active-server hierarchy, resource- manager hierarchy, and a memory-manager hierarchy.

2. Examples of System Models

Introduction

This chapter illustrates the application of the heirarchical modeling process to construct a sophisticated model of a computer system. The model is developed iteratively. A simple model of the system is constructed initially. Subsequently, each iteration refines the model either by decomposing a sub-model into a collection of sub-models or by refining a sub-model to introduce complexity in its description.

2.1 Example 1: Batch Server System

As our first example, we choose a simple batch processing system. In the physical system, users submit their jobs to an operator who queues each job for execution by the computer. After a job has been executed, the output is sent to one of several identical line printers where it is printed and is subsequently picked up by the user.

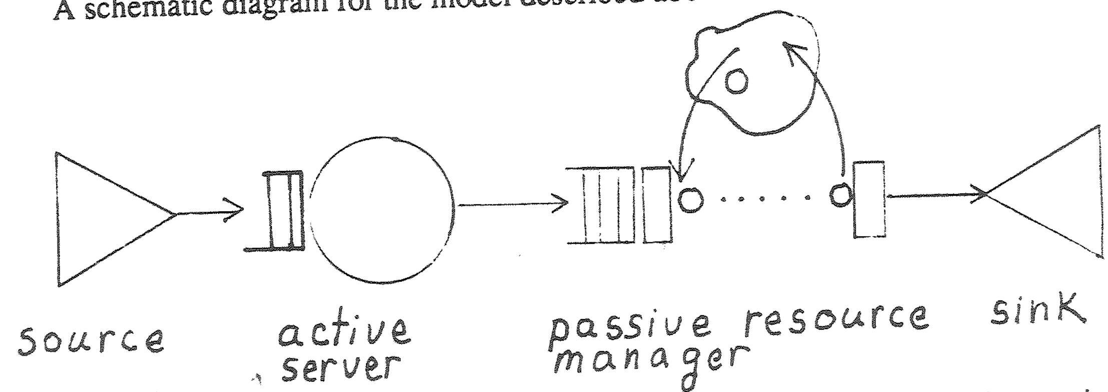
We develop a simple model of the physical system described above. The *source* entity models the arrival of the batch jobs at the computer. This entity creates jobs at a specified rate which is equal to the average rate at which students submit their jobs to the operator.

The operator and the computer are modeled by a simple entity called *izasl2*. *Izasl2* is the simplest entity from a family of entities known as the *active-server* family. This entity (at the first level of the heirarchy) services requests using a *fcfs* service discipline. The entity has a simple parameter called its service rate which specifies the fixed rate at which requests for service are processed.

To model access to a group of line printers, a *resource* entity, *iztmf1*, is chosen from the *passive-resource-manager* family. This entity models exclusive access to one or more of the passive resources (line printers) that it manages. The entity is the simplest entity in this family and models access to a simple type of resource. The entity has a simple parameter *numtok* which specifies the initial number of units of the resource managed by the manager. Upon receipt of a request, the manager services the request if enough units of the resource are available. Otherwise the request is queued. A queued request is serviced in a fcfs fashion when sufficient units of the resource become available to the manager.

Finally the *sink* entity models the departure of jobs from the system (i.e. students picking up hard output).

A schematic diagram for the model described above follows:



A special entity called the *job* entity is defined to simulate the interactions between the user and the system. A *job* entity is created by the *source*. After having been created, a job first requests service from the computer and waits for acknowledgement that the service has been completed. It then requests and waits for access to a single line printer. After obtaining access, the job retains access to the printers for a time specified by the job. After its output has been printed, the job relinquishes access to the printers and terminates.

The statistical information generated by the execution of this model is 1) utilization of the computer which is defined as the % of time the *cpu* was servicing requests; 2) utilization of the line printers which is the average number of line printers that were in use over the entire simulation period; and 3) the mean response time for requests which is defined as the average time for a *job* entity to receive service from the *cpu* entity and the *resource* entity. The first two statistical measures are automatically generated by the respective entities. The third statistic is incorporated in the description of the *job* entity.

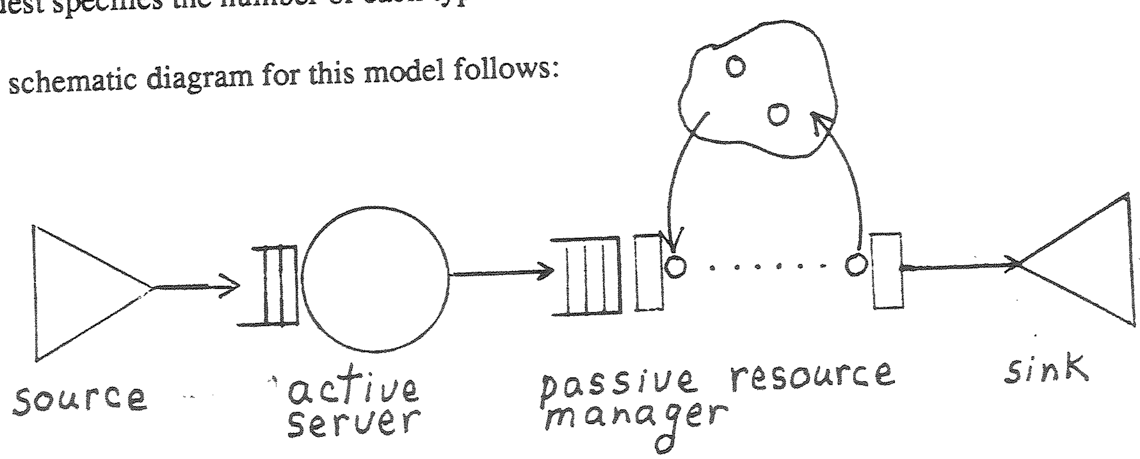
2.2 Example 2: Batch Server System With Two Types of Printers

For our second example, we refine the batch processing system introduced in example one to introduce two types of printers. After a job has been executed by the computer, it may be directed to one of two types of printers - laser printers or line printers.

To model this system, the *source, sink* and *computer* components and their respective attributes remain as described in the previous example. The printer component and its attributes change as described below.

To model access to two different types of printers, an entity called *iztmf2* is chosen from the second level of the *passive-resource-manager* family. When the *resource* entity receives a request for access to the passive resources (printers), if enough units of the type of resource requested is available, the request is granted. Otherwise the request is placed on a time of arrival (First-Come-First-Serve) queue. In general, a request specifies the number of each type of resource managed by the entity.

A schematic diagram for this model follows:



The only change in the *job* entity is that it must now specify which type(s) of passive resources (printers) it requires. The *job* releases these resources after retaining access for a time specified in its description.

The statistics gathered remain the same as in the first example.

2.3 Example 3: Interactive Server System

In this example, we assume that the system being modelled is an interactive computer system. In the physical system, users at interactive terminals use a computer to create documents and then print them out on laser or line printers. The components of the system are : users of the computer, terminals, the computer, and the printer manager and the printers. Actions performed by the components are described below.

A user logs on to a terminal and sends commands to the computer in order to create a document. The user sends an arbitrary number of editing commands followed by a request to print the final document when he or she is finished. The computer executes the commands and informs the user when the execution is completed. When a computer receives a request to print a document, it forwards the request to the printer manager which controls access to the laser and line printers, ensuring that only one document is being printed on a given printer at any time.

The users of the system are classifed as undergraduate students, graduate students, or professors. User commands are executed according to the priority of the user. Professors have the highest priority, then graduates, and then undergraduates. The priority of each user is determinable from the logon id of the user.

A simulation model of the physical system described above is constructed as follows. We assume that each user thinks for a while, then issues a single command to the computer from the terminal. The command *requests* service from the computer. The computer services the user's request according to the user's priority. The number of editing commands requested by a user (before the final print command) is determined according to a probability distribution. Each request of the user is preceded by a thinking phase before entering his or her next command. If the user is finished editing his or her document, then the last request made will be to have it printed on a laser or line printer. A request is sent, containing the user's id, to the printer manager.

When the printer manager receives a printer request, it releases the type of printer needed to the computer so that the document can be printed. If a printer of the appropriate type isn't available, the manager queues the request according to the user's priority and services it when a printer is available. After the user's document has been printed, the printer is released and the user leaves the system.

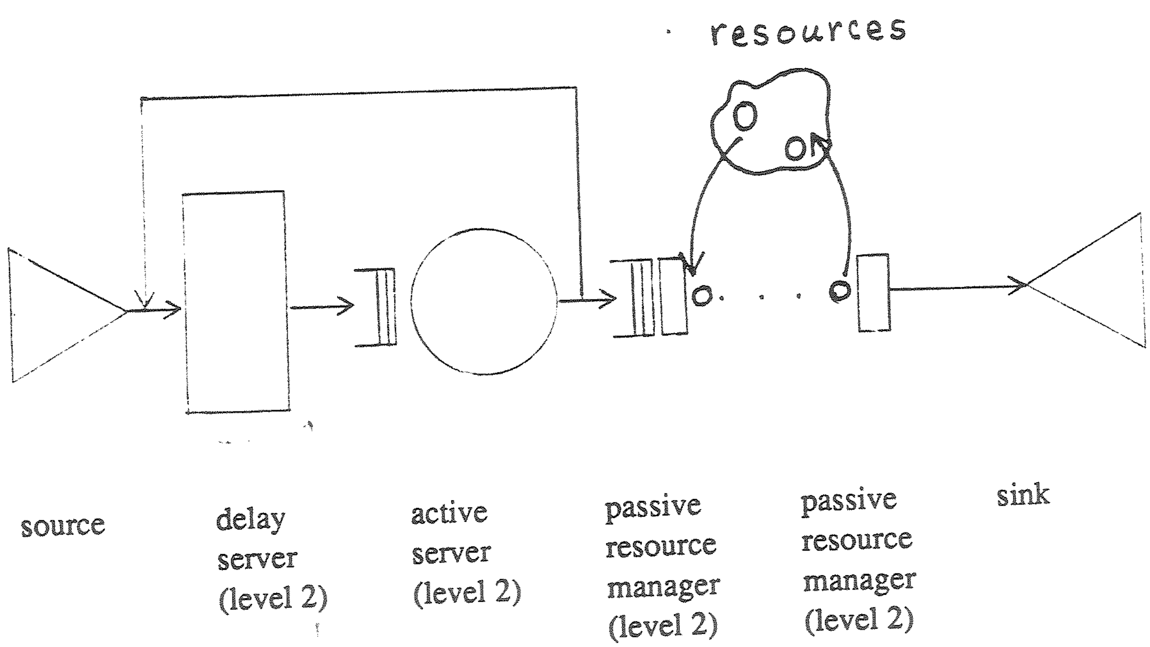
For the simulation model, entities are created which model both the components of the physical system (on a very simple level) and the actions taken by a user in editing and printing a document. The model consists of the following entities: the *source* which models arrivals; three entities to model the three hardware components and the document-creation actions to be modeled (i.e. the interactive terminals, the computer, and the printer manager for the laser and line printers); the users are modeled by an entity called the *job* entity. When the *job* departs from the system, it is said to have reached the *sink* (For this, as in previous examples, the *sink* does not need to be modeled as an actual entity).

The first entity to consider is the one needed to model the interactive terminals and the process of users thinking and entering commands. Two points need to be considered in choosing this entity. First, the thinking time of the user must be simulated. Second, the users are able to log on to an available terminal and immediately receive service. For the purpose of this example, the number of users in the sytem is never greater than the number of available terminals. A *delay service center* from level 2 of the *active server hierarchy*, *izasdy*, will be chosen. The thinking time of the users can be easily simulated as a *service request* to the delay server. Further, a delay server allows a user to receive immediate service without waiting, no matter how many users are already being serviced. The statistics that will be gathered by the delay server will be: the minimum, maximum and mean think times, the utilization of the server, and the server throughput.

The second entity is used to simulate the computer. In this case, the computer services one user at a time using a *priority* service discipline. Another *active server* entity, called *izasl2* from level two of the active server hierarchy can be used to simulate the computer. This entity has two parameters, the *service rate* which is the rate, in service units per simulation unit, that service requests are satisfied; and the *service discipline* which for this example has been specified as a *priority service* discipline. The commands received by the computer can be simulated as requests for service from the user to the *izasl2* entity. The statistics that will be gathered by the *izasl2* server will be: the minimum, maximum and mean response and service times, the utilization of the server, the maximum and mean queue length, and the server throughput.

The third entity simulates the printer manager and the printers. As in example two, a level two *passive resource manager, iztml2*, can be used, except that the *queueing discipline* will be specified as priority.

A diagram and complete description of the simulation model just constructed follows:



Finally, the job entity description. The *source* creates jobs according to the interarrival rate. Each job requests service from the *delay server* corresponding to the average 'think time' of the user. Upon completion of the service from the *delay server*, a service request is sent to *izasl2*. The request is queued according to job priority. Upon completion of the service request, the job either requires more service and again requests service from the *delay server* followed by a request to *izasl2*, or a resource request containing the resource type and the job's priority is sent to the *passive resource manager*. The probabilty of a job returning to the *delay server* is $p1$ and the probability of going on to *izasl2* is $p2$. If a resource of the correct type can be allocated, it is; otherwise the request is queued. The *passive resource manager* allocates a resource to the job which the job keeps for a time period simulating resource usage, then returns the resource to the *passive resource manager*. Finally, the job proceeds to the *sink* and terminates. At this point the response time statistics for the job are gathered.

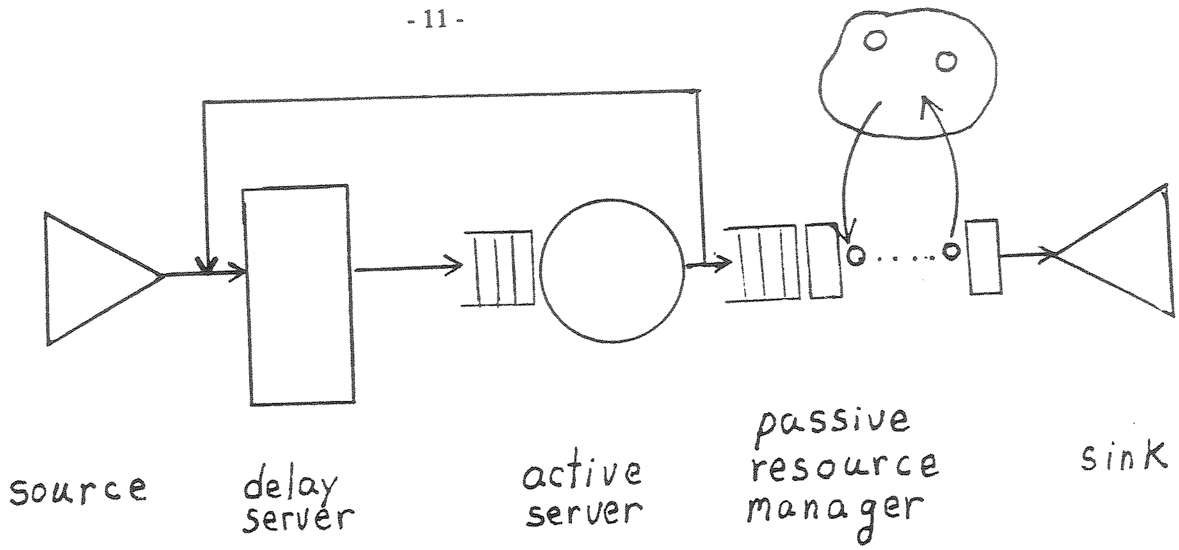
2.4 Example 4: Interactive System with Revisions

For this example, we refine the model for the interactive system introduced in example 3. The refinements introduced in this example model a computer that services requests using a pre-emptive priority service discipline. The queue length is controlled to limit the number of requests in the queue. A final refinement is that the printer manager now schedules requests for access to the passive resources (printers) using a priority discipline.

In the pre-emptive priority discipline, a server services its queue according to the priority of the request. If a request with a higher priority is received by the server while it is servicing a lower priority request, the request being serviced is pre-empted and the higher priority request is serviced. The pre-empted request is put on the priority queue of the server.

The components or aspects of this system which change from the previous example are the following: the users and the terminals (source); the computer's associated queue of requests which is maintained in a *pre-emptive priority* scheduling discipline; the queue capacity (maximum number of requests in the queue) is now specifiable; and access to the printers which is given according to a *priority* discipline. The following components or aspects remain as described in example 3: the computer; the routing (back to terminals or to printer); and the sink.

A schematic diagram of the model follows:



To model the computer with *queue capacity* and which schedules requests using a *pre-emptive priority* discipline, a server called *izasl3* is chosen from the third level of the *active-server* family. The statistics gathered by this entity are: the minimum, maximum and mean response times; the utilization of the server; the minimum and maximum queue length; and the server throughput.

An entity *iztml2* is chosen from the second level of the *passive-resource-manager* family to model the printer manager and the queues associated with each type of printer. At this level of the heirarchy, the desired *priority* scheduling discipline may be specified. The statistics gathered by this entity are the same as for example two.

The description of the *source* entity changes slightly to accomodate the capability to specify the queue capacity. This change is effectuated by the specification of the entity parameter, *quecap*, when instantiating the active server, *izasl3*. The *job* entity must specify the priority of the requests to both the active and passive servers.

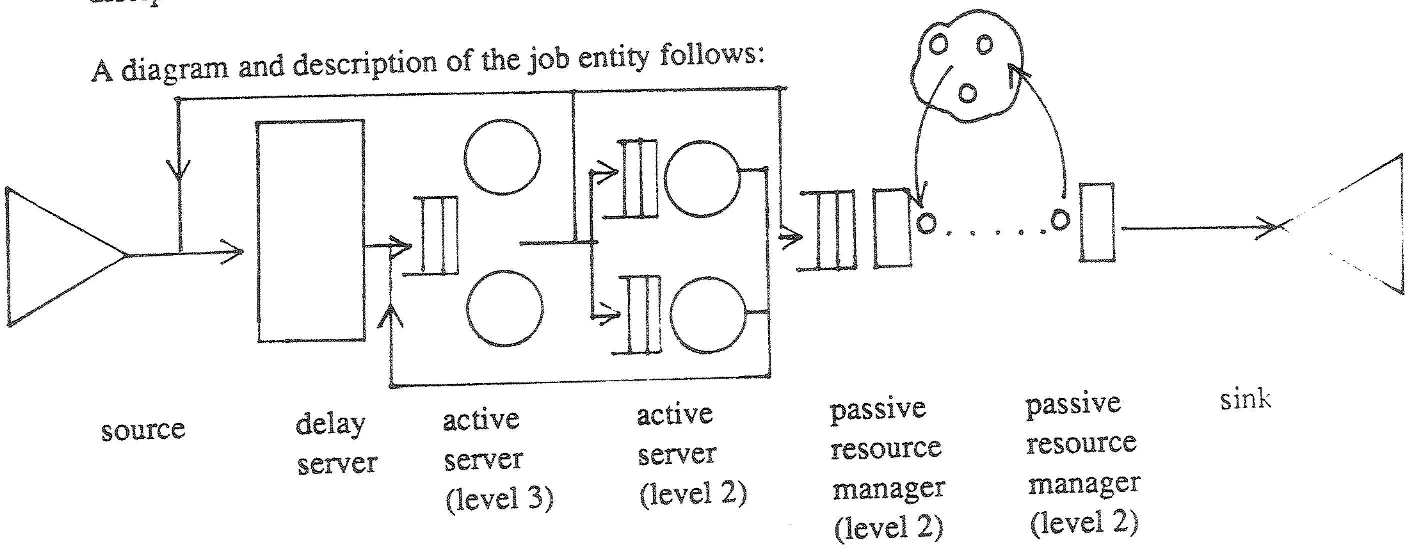
2.5 Example 5: Interactive System With Dual Processor

For this example, there are two significant additions to the system to be modeled. First,the single processor computer is replaced by a dual-processor computer. The order in which service requests are executed remains the same i.e. pre-emptive priority, however there are now two processors servicing requests from a common queue. Second, user documents are retrieved from and saved on disk drives. Two disks are available, both of equal service rates; the cpu accesses the disks to update and store documents. The components of the system are now: users of the computer, terminals, the dual-processor computer, the two fcfs disk drives and the printer manager and the printers.

The entity needed to model this dual-processor computer must have two identical servers to simulate the two processors, the ability to set the *queue capacity*, and a *pre-emptive priority* queueing discipline. Again, a level three *active server* entity, *izasl3*, is chosen from the *active server* hierarchy. The number of servers parameter is set to two. The statistics that will be gathered by *izasl3* will be: the minimum, maximum and mean response and service times, the utilization of the server, the maximum and mean queue length, and the server throughput.

The disks will each be modeled by a level 2 *active server* entity with *fcfs* service discipline.

A diagram and description of the job entity follows:



The principle change in the *job* entity from previous examples is that it must define the routing of a transaction to the several possible active servers and the passive resource manager. In order to do this, branching probabilities, *p1,p2,p3,p4* are defined to determine whether the job proceeds to *the level two active servers, the passive resource manager* or back to the *delay server*, respectively. As in the previous examples, the response time statistics gathered by the *job* entity are a measure of the length of time from the *job's* creation to its departure from the system.

3. Active Resource Manager Heirarchy

3.1 Description of Active Server Attributes

The active server hierarchy is based upon the increasing capability of the service center to model more diverse and complex servers. The capabilities of the service center at each level of the hierarchy are indicated by attributes and the range of attribute values available to the user at each level.

The simplest attributes of a server, available at level 1, are service rate and service discipline. Service rate determines the fixed rate at which customer requests for service are satisfied. This rate is assumed to be expressed in number of service units per unit of simulation time. For example a service rate of 10000 means that each customer will recieve 10000 units of service for each unit of simulation time. The service discipline refers to the order in which requests for service are handled by a service center. The two types available at level 1 are first-come-first-served and priority.

Level 2 of the active server hierarchy extends the scope of service disciplines to include the delay or infinite server. When using this discipline, a customer never waits for service. Level 2 introduces two new attributes, server power and queue status. Server power can be used to vary the service rate of a server. At this level, the power may be set on or off. Queue status allows a server to dynamically close and open its queue. When queue status is off, the server will not accept any further requests.

At level 3, two new service disciplines, and three new attributes, including multiple servers become available to the user. Level 3 introduces two new service disciplines, last-come-first-served- preemptive-resume and preemptive priority. For lcfspr: if, when a customer arrives at the manager with a service request, all servers are busy, then the customer that has been serviced the longest is pre-empted and the new customer is allocated that server. For preemptive priority, if a request entering the server's queue has a higher priority than a current customer, then the higher priority request may preempt the lower. Level 3 also introduces a user-specifiable queue capacity which limits the number of customers that can join the server queue. When the queue capacity is reached, customers can no longer join the queue. In addition, switching over- head to simulate switching service between customers is available at level 3. Finally, at level 3 the number of servers available at the service center becomes user specifiable. Once specified, the number of servers at the center cannot be changed, although specific servers may be turned on or off using the server power attribute, which can now be used to separately modify the power of each server.

Level 4 adds two new service disciplines, round robin and processor sharing. For round robin, each entering customer joins the queue, which is treated as if it were circular. Service is provided to each requestor by going around the queue, giving each a fixed quantum of service. For processor sharing, a variable interval of service time is shared evenly among all requestors currently in the server queue.

Level 5 introduces a modifiable service rate attribute, and two new attributes, server priority and queue inspection by requestors. At level 5, the service rate attribute becomes dynamically modifiable, relative always to the original,user-specified, service rate. When multiple servers are available at a service center, a different service rate can be initially specified and separately modified for each server. Multiple servers at a service center can be assigned priorities for handling incoming requests at level 5, using the new server priority attribute. Server priority indicates which server(s) will handle an incoming request first when more than one server is on and idle. The second new attribute is queue inspection, which allows a customer to inspect the queue and balk (choose not to request service) if,for example, the queue is too long.

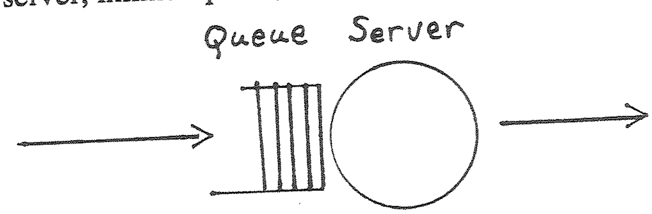
Level 6 increases the queue-status-dependent capabilities of a customer by allowing a queued requestor to reneg and leave the queue. Level 6 also allows a customer to express affinity for a particular server(s) the customer would prefer to be serviced by.

At level 7, the basic server attributes of service discipline and service rate become user-specifiable algorithms.

3.2 Active Server Conceptual Models(levels 1 - 3)

3.2.1 Level One

(single server, infinite queue)



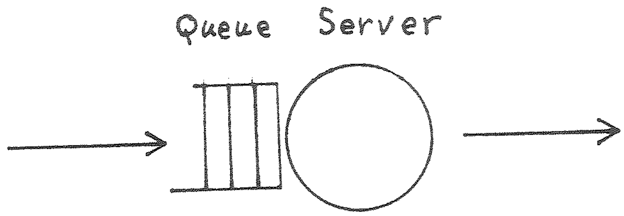
A customer arrives at the service center needing a certain number of units of service. The customer immediately joins the queue, and while in the queue recieves the service. The customer then departs the service center. Service is provided to one customer at a time by a single server. The server provides sevice at a fixed rate. The service discipline determines the order in which customers are served.

Active server center attributes:

*	**service rate**	integer >= 0 (service units/time unit)	1	static
*	**service discipline**	{fcfs,priority}	fcfs	static

3.2.2 Level Two

(single server, infinite queue, dynamic server power and queue status)



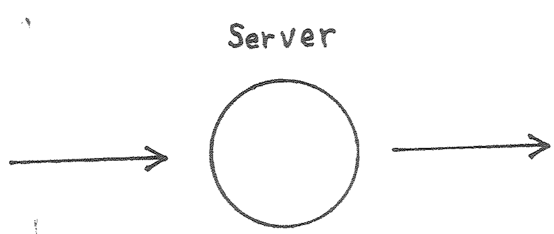
A customer arrives at the service center needing a certain number of units of service. The customer immediately joins the queue, and while in the queue recieves the service. The customer then departs the service center. Service is provided to one customer at a time by a single server. The server provides service at a fixed rate. The service discipline determines the order in which customers are served. Both the queue an the server may be dynamically made inoperable. Customers receive no service if the server is off, although customers can continue to join the queue if it is open. Customers are denied entry to a closed queue, although customers already in the queue continue to receive service if the server is on.

Active server center attributes:

*	**service rate**	integer >= 0 (service units/time unit)	1	static
*	**service discipline**	{fcfs,priority}	fcfs	static
*	**server power**	{on,off}	on	dynamic
*	**queue status**	{open,closed}	open	dynamic

3.2.3 Level Two

(delay)



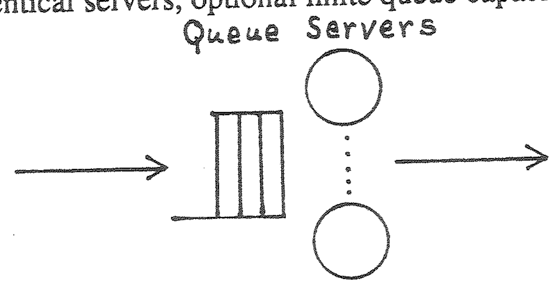
Same as the other service centers at this level, except that service is provided to each customer as if it were the only customer at the service center. A customer never waits while other customers are being served.

Active server center attributes:

*	**service rate**	integer >= 0 (service units/time unit)	1	static
*	**service discipline**	{delay}		static
*	**server power**	{on,off}	on	dynamic

3.2.4 Level Three

(multiple identical servers, optional finite queue capacity)



Service may be provided to customers by multiple identical servers. All servers operate at the same fixed rate, although each server may be independently turned on or off. Additional service disciplines are available. The maximum number of customers that can wait in the queue can be specified by setting the queue capacity. Queue status and queue capacity are independent. A queue of any capacity can be closed at any length.

Active server center attributes:

*	**service rate**	integer >= 0 (service units/time unit)	1	static
*	**service discipline**	{fcfs,priority}	fcfs	static
*	**new service disciplines**	{lcfs preempt-resume, preemptive priority}		static

*	**server power**	{on,off}	on	dynamic
*	**queue status**	{open,closed}	open	dynamic
*	**number of servers**	integer >= 1	1	static
*	**queue capacity**	integer >= 1	infinite	static

4. Passive Resouce Manager Heirarchy

4.1 Description of Passive Resource Manager Attributes

A passive resource center manages a pool of resources available to requesting customers. The attributes of a resource manager are resource types and the resource allocation discipline. Resource types refers to the number of different types of resources managed by a resource manager. The resource allocation discipline refers to the manner in which incoming requests for resources are serviced.

At level 1, one resource type is available, and the initial size of the resource pool is specifiable by the user. The allocation disciplines that can be used are first-come-first-served, priority, and skipping. The skipping discipline allows satisfiable requests queued behind unsatisfiable requests to be allocated resources.

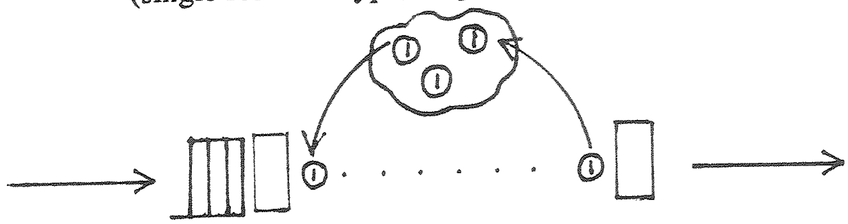
At level 2, the number of resource types becomes specifiable by the user, each type has its own pool, and the initial size of each pool can be set by the user. Additionally, each requestor now includes requests for each type in its resource request.

At level 3, the requestor is allowed to include alternative sets of requests for resources of each type.

4.2 Passive Resource Manager Conceptual Models

4.2.1 Level One

(single resource type, single user request)



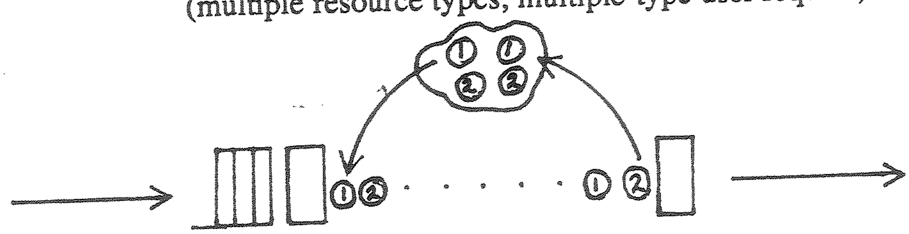
A customer requiring passive resources arrives at the passive resource manager. The requestor enters the manager's queue, and is serviced according to the manager's allocation discipline: fcfs, priority or skipping. On acquiring the required number of resources, the customer leaves the manager. The customer may subsequently return to the manager and release resources back to the manager without entering the manager's queue.

Passive resource center attributes:

*	**initial pool of resources**	integer >= 0	infinite	static
*	**queue type**	{fcfs,priority}	fcfs	static
*	**user request type**	integer variable		dynamic

4.2.2 Level Two

(multiple resource types, multiple-type user request)



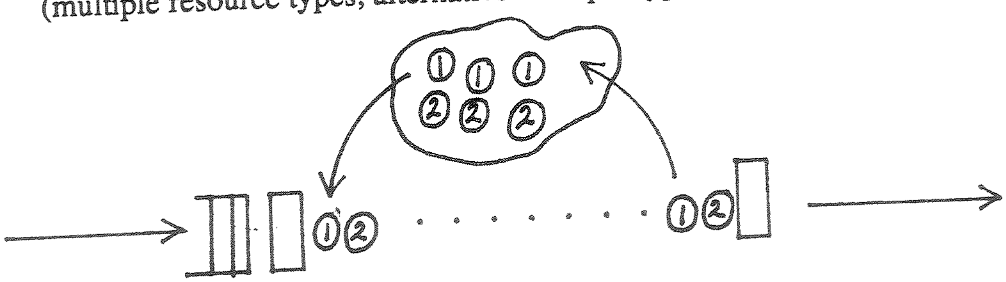
A customer requiring passive resources arrives at the passive resource manager. The requestor enters the manager's queue, and is serviced according to the manager's allocation discipline: fcfs, priority or skipping. The passive resource manager has more than one type of resource available, and a customer indicates in its request how many resources of each type is needed. If enough resources of each type are available in the resource pools, then the customer is allocated the requested number of resources of each type. On acquiring the required number of resources, the customer leaves the manager. The customer may subsequently return to the manager and release resources back to the manager without having to enter the manager's queue. When a customer releases resources back to the resource manager, the number of resources that are being returned of each type are specified.

Passive resource center attributes:

*	**initial pool of resources**	vector of integer >= 0	infinite	static
*	**queue type**	{fcfs,priority, skipping}	fcfs	static
*	**number of resource types**	integer >= 1	1	static
*	**user request type**	vector of integer >= 0		dynamic

4.2.3 Level Three

(multiple resource types, alternative multiple-type user requests)



A customer requiring passive resources arrives at the passive resource manager. The requestor enters the manager's queue, and is serviced according to the manager's allocation discipline: fcfs, priority or skipping. The passive resource manager has more than one type of resource available, and a customer needing resources of these types presents the resource manager with a request that contains alternative sets of requests.

Each set contains a single request value for each resource type available. If enough resources of each type are available in the resource pools to satisfy one of the sets of requests, then the customer is allocated the requested number of resources of each type. On acquiring the required number of resources, the customer leaves the manager. The customer may subsequently return to the manager and release resources back to the manager without having to re-enter the manager's queue. When a customer releases resources back to the resource manager, the number of resources that are being returned of each type are specified.

Passive resource center attributes:

*	**initial pool of resources**	vector of integer >= 0	infinite	static
*	**queue type**	{fcfs,priority, skipping}	fcfs	static
*	**number of resource types**	integer >= 1	1	static
*	**user request type**	matrix of alternative vectors of integer >= 0		dynamic

5. Shared Memory Manager Heirarchy

5.1 Description of Memory Manager Attributes

The memory manager manages access to blocks of simulation memory. Two types of blocks are managed: 1) Free blocks which are available for data storage and 2) data blocks which contain previously stored data. The memory manager receives requests to allocate free blocks, allocate data blocks, or release a data block.

At the simplest level of the heirarchy(level 1), the only attribute that is specifiable by the user is memory size.

At level 2, the user is given the additional capability of specifying the service discipline for the manager. The service discipline refers to the order in which requests for data and free blocks are serviced. Although the requests for free blocks and data blocks are kept in separate queues, the discipline specified applies to both.

In addition to the attributes at the first two levels, at level 3, the user may specify the memory allocation strategy. This attribute determines the method by which free blocks of simulation memory is allocated. The methods provided are first-fit and best-fit. For the first-fit strategy, the first block available which satisfies the request is returned. For the best-fit strategy, the request is filled by the smallest block large enough to satisfy the request. This implies that the list of free blocks is ordered on size.

5.2 Shared Memory Heirarchy Conceptual Models:

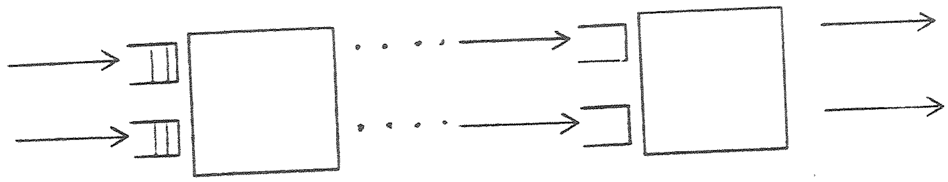
5.2.1 Level One

A customer requesting either a Free block or Data block immediately joins a queue and is serviced (or terminated) in finite time. The customer leaves the manager upon receiving the desired amount of memory.

Memory Manager Attributes:

*	**memory size**	integer >= 1	static

5.2.2 Level Two

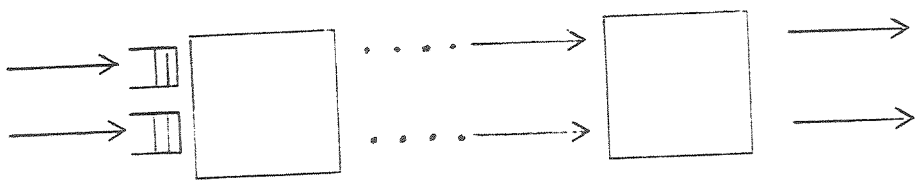


A customer request for Data or Free blocks is serviced according to the specified queueing discilpline - either fcfs or priority.

Memory Manager Attributes:

*	**memory size**	integer >= 1		static
*	**service discipline**	{fcfs,priority}	fcfs	static

5.2.3 Level Three



The strategy for the allocation of simulation memory may also be initially specified.

Memory Manager Attributes:

*	**memory size**	integer >= 1		static
*	**service discipline**	{fcfs,priority}	fcfs	static
*	**allocation strategy**	{bestfit,firstfit}	bestfit	static

6. Code For The Examples

6.1 Notes on the Example Code

6.1.1 Functions used in the example simulation programs

The following functions are used by the example programs :

expon(mean) : given a *mean* value of type integer, generates a random number according to the exponential probability distribution. The value returned is of type real.

prbgen(array,size) : given an array of cumulative probabilities and the size of the array, returns an index to one of the cumulative probability values. *Array* should be of type real and *size* of type integer. The returned index is of type integer. The intrinsic function rand() is used.

cstore(cvar1,cvar2) : copies the value of *cvar2* into *cvar1*. Both variables should be of type clocktype.

csub(cvar1,cvar2) : given two variables of clocktype, returns the value of *cvar1* minus *cvar2*. The return value is of type integer.

6.1.2 Entity family reserved words used in the examples

The following reserved words are used by the example simulation programs. They are located in *common.sim*. For a description of the MAY reserved words, please consult the *MAY User Manual*.

fcfs : first-come-first-served service discipline flag.
prirty : priority service discipline flag.
prepri : pre-emptive priority service discipline flag.

6.2 Code and Results

6.2.1 Code for Example One

```
c*********************************************************************
c*
c*              E N T I T Y       S O U R C E
c*
c*   FUNCTION:
c*      This is the source entity which creates transactions according
c*      to a specified interarrival rate.
c*      Transactions are created until SOURCE is terminated.
c*
c*   PARAMETERS:
c*      CPU: cpu active server entity id.
c*      PRNMGR: printer manager entity id.
c*      STAT1: statistics entity id.
c*
c*   MESSAGES:
c*      TRMNT: Message to terminate the entity-instance.
c*
c*********************************************************************
        entity source(cpu,prnmgr,stat1)

        local integer jobcnt,intarr
        integer trans
        real expon

        message trmnt

c*      set interarrival rate
        intarr = 3000
        jobcnt = 0

c*      create transactions until terminated by main
10      continue
        let trans be job(cpu,prnmgr,stat1)
        jobcnt = jobcnt + 1
        wait int(expon(intarr))
        if (msg .ne. trmnt) go to 10

        write(6,9000)jobcnt
9000    format(//"Source Termination.",
     +          /,"Number of transactions created by source = ",i6)

        ende


c*********************************************************************
c*
c*              E N T I T Y     J O B
c*
c*   FUNCTION:
c*      This is the transaction entity.
c*
c*   PARAMETERS:
c*      CPU: cpu active server entity id.
c*      PRNMGR: printer manager entity id.
c*      STAT1: statistics entity id.
c*
c*   MESSAGES:
c*      RQCOMP: Request for service completed.
c*      HAVTOK: Have been allocated resource requested.
c*
c*********************************************************************
        entity job(cpu,prnmgr,stat1)

        integer cpumn,prnmn,numres,csub
```

```
c*      mean service times for cpu & printer,number of resources needed
        parameter(cpumn = 50, prnmn = 4000,numres = 1)
        real expon
        clocktype begclk

        message rqcomp
        message havtok

c*      trace 3 when .true.
c*      record starting time token for response stat
        call cstore(begclk,clock)

c*      request service from computer
        invoke cpu with reqest(myid,int(expon(cpumn)))

c*      wait for service complete message
        wait maxint for (msg .eq. rqcomp)

c*      request printer
        invoke prnmgr with reqtok(myid,numres)
c*      wait to receive resource
        wait maxint for (msg .eq. havtok)
c*      simulate printer usage
        wait int(expon(prnmn))
c*      return printer to manager
        invoke prnmgr with reltok(myid,numres)

c*      collect service stat
        invoke stat1 with insert(csub(clock,begclk))
999     continue
        ende

c***********************************************************************
c*
c*               E N T I T Y        M A I N
c*
c*      This is entity main which creates the active servers, passive
c*      resource manager, statistics entity, and source entity.
c*
c***********************************************************************
        entity main

        local integer cpu,prnmgr,stat1
        integer srvrte,initrs,title(26),titlen
c*      service rate 1 sim unit   = 1 msec,initial resources = 2
        parameter(srvtre = 1, initrs = 2,titlen = 26)
        include 'common.sim'
        data title/'T','R','A','N','S','A','C','T','I','O','N',' ',
     +          'R','E','S','P','O','N','S','E',' ','T','I','M','E','S'/

        message

c*      trace 3 when .true.
        write(6,9000)
9000    format(/,"Start of Simulation."/)
c*      set izstim to simulation run length
        simulation period 500000
        izstim = 500000

c*      set up statistics entity for job response time
        let stat1 be mnstat(titlen,title)
c*      create cpu activer server and printer resource manager
        let cpu be izasl2(fcfs,srvrte)
        let prnmgr be iztmf1(initrs)
c*      create source
```

```
      let src be source(cpu,prnmgr,stat1)
c*    run for simulation period
      wait izstim

c*    dump statistics
      invoke stat1 with dump(6)
      invoke cpu with dump(6)
      invoke prnmgr with dump(6)

c*    terminate cpu,prnmgr,source,stat1
      invoke cpu with trmnt
      invoke prnmgr with trmnt
      invoke src with trmnt
      invoke stat1 with trmnt

      write(6,9001)
9001  format(/,"Simulation has finished.")
      ende

c*    append informs MAY compilier of needed entities
      append izasl2,iztmf1,mnstat
```

6.2.1 Results for Example One

```
start of simulation.

simulation has finished.

 statistical dump at simulation time        500000.

                                 transaction response times
 the total of all values is        838267.
 the total no. of values is         158
 the average value is        5305.49

 statistical dump at simulation time :     500000


System statistics for active server

 Server type = fcfs

 Service rate =       1
 Number of servers =       1

 response time
        min          max               mean           number

         1            236              53.019          160

 service time
        min          max               mean           number

         1            236              52.763          160


 Queue length statistics:
 total jobs at server = jobs being serviced + jobs waiting
         mean                max        current

         0.017                2            0


 System statistics :

        utilization       thruput        jobs completed     jobs pre-empted

         0.017             0.000            160                        0

 statistical dump at simulation time :     500000


 System response time stats for token requests:

 Initial number of tokens:      2

 minimum response time :       0
 maximum response time :   11496
 number of responses   :     160
 mean response time    :    1484

 System throughput      :     0.00032
 mean queue length      :    0.47514
 mean available tokens (all types):    0.80533
```

```
 jobs still in queue :      0

source termination.
number of transactions create by source =    160
 Simulation terminated normally
 Simulation period specified:        500000.
```

6.2.1 Code for Example Two

```
c***********************************************************************
c*
c*             E N T I T Y        S O U R C E
c*
c*   FUNCTION:
c*      This is the source entity which creates transactions according
c*      to a specified interarrival rate.
c*      Transactions are created until SOURCE is terminated.
c*
c*   PARAMETERS:
c*      CPU: cpu active server entity id.
c*      PRNMGR: printer manager entity id.
c*      STAT1: statistics entity id.
c*
c*   MESSAGES:
c*      TRMNT: Message to terminate the entity-instance.
c*
c***********************************************************************

        entity source(cpu,prnmgr,stat1)

        local integer jobcnt,intarr
        integer trans
        real expon

        message trmnt

c*      set interarrival rate
        intarr = 3000
        jobcnt = 0

c*      create transactions from job entity
10      continue
        let trans be job(cpu,prnmgr,stat1)
        jobcnt = jobcnt + 1
        wait int(expon(intarr))
        if (msg .ne. trmnt) go to 10

        write(6,9000)jobcnt
9000    format(//,"Source Termination.",
     +          /,"Number of tranasctions created by source = ",i6)

        ende
c***********************************************************************
c*
c*             E N T I T Y        J O B
c*
c*   FUNCTION:
c*      This is the transaction entity.
c*
c*   PARAMETERS:
c*      CPU: cpu active server entity id.
c*      PRNMGR: printer manager entity id.
c*      STAT1: statistics entity id.
c*
c*   MESSAGES:
c*      RQCOMP: Request for service completed.
c*      HAVTOK: Have been allocated resource requested.
c*
c***********************************************************************
        entity job(cpu,prnmgr,stat1)

        real x,lasprb,expon
        integer cpumn,prnmn,linepr,lasprn,prbgen,csub
```

```
c*      mean service times for cpu & printers,resource array indices,
c*      laser printer probability
        parameter(cpumn=50, prnmn=4000,linepr=1, lasprn=2,lasprb=0.20)
        local integer prntyp(2)
        clocktype begclk

        message rqcomp
        message havtok

c*      trace statement
c*      trace 3 when .true.

c*      record starting time token for response stat
        call cstore(begclk,clock)

c*      request service from computer
        invoke cpu with reqest(myid,int(expon(cpumn)))
c*      wait for service complete message
        wait maxint for (msg .eq. rqcomp)

c*      request printer
c*      decide upon printer to use according to probability of laser
c*      set resource array slots to number of each type of resource needed
        prntyp(linepr) = 0
        prntyp(lasprn) = int(rand(x)+lasprb)
        if (prntyp(lasprn) .eq. 0 ) prntyp(linepr) = 1
        invoke prnmgr with reqtok(myid,prntyp[2])
c*      wait to acquire resource
        wait maxint for (msg .eq. havtok)
c*      simulate printer usage
        wait int(expon(prnmn))
c*      return printer to manager
        invoke prnmgr with reltok(myid,prntyp[2])

c*      collect service stat
        invoke stat1 with insert(csub(clock,begclk))
999     continue
        ende

c************************************************************************
c*
c*              E N T I T Y         M A I N
c*
c*      This is entity main which creates the active servers, passive
c*      resource manager, statistics entity, and source entity.
c*
c************************************************************************

        entity main

        integer initrs,nmres,resors(2),srvrte,title(26),titlen
c*      set initial resource, service rate, number of resources
        parameter(initrs = 2,srvtre = 1,nmres = 2,titlen=26)
        local integer cpu,prnmgr,stat1,src
        clocktype begclk
        include 'common.sim'
        data title/'T','R','A','N','S','A','C','T','I','O','N',' ',
     +          'R','E','S','P','O','N','S','E',' ','T','I','M','E','S'/

        message

c*      trace 3 when .true.
        write(6,9000)
9000    format(/,"Start of simulation.",/)

c*      set simulation period and izstim
```

```
      simulation period 500000
      izstim = 500000

c*    initialize initial-resources array for resource manager
      do 10, i=1,nmres
         resors(i) = initrs
10    continue

c*    set up statistics entity for response time collection
      let stat1 be mnstat(titlen,title)

c*    create cpu activer server and printer resource manager
      let cpu be izasl2(fcfs,srvrte)
      let prnmgr be iztmf2(nmres,resors)

c*    create jobs
      let src be source(cpu,prnmgr,stat1)
c*    run for simulation period
      wait izstim

c*    dump statistics
      invoke stat1 with dump(6)
      invoke cpu with dump(6)
      invoke prnmgr with dump(6)

c*    terminate cpu,prnmgr,stat1,src
      invoke cpu with trmnt
      invoke prnmgr with trmnt
      invoke src with trmnt
      invoke stat1 with trmnt

      write(6,9001)
9001  format(/,"Simulation has finished.")

      ende

c*    append informs MAY compilier of needed entities
      append izasl2,iztmf2,mnstat
```

6.2.1 Results for Example Two

start of simulation.

simulation has finished.

statistical dump at simulation time 500000.

transaction response times

the total of all values is 1019225.
the total no. of values is 175
the average value is 5824.14

statistical dump at simulation time : 500000

System statistics for active server

Server type = fcfs

Service rate = 1
Number of servers = 1

response time

min	max	mean	number
0	260	48.497	177

service time

min	max	mean	number
0	260	48.497	177

Queue length statistics:
total jobs at server = jobs being serviced + jobs waiting

mean	max	current
0.017	1	0

System statistics :

utilization	thruput	jobs completed	jobs pre-empted
0.017	0.000	177	0

statistical dump at simulation time : 500000

System response time stats for token requests:

Token type: 1 initial tokens: 2

Token type: 2 initial tokens: 2

minimum response time : 0
maximum response time : 9226
number of responses : 177
mean response time : 1514

Token type: 1 mean available tokens: 0

```
 Token type:    2 mean available tokens:      1

 System throughput      :    0.00035
 mean queue length     :    0.53605
 mean available tokens (all types):    2.51000

 jobs still in queue :      0


source termination.
number of tranasctions created by source =    177
 Simulation terminated normally
 Simulation period specified:        500000.
```

6.2.1 Code for Example Three

```
c*********************************************************************
c*
c*              E N T I T Y        S O U R C E
c*
c*   FUNCTION:
c*      This is the source entity which creates transactions according
c*      to a specified interarrival rate.
c*      Transactions are created until SOURCE is terminated.
c*
c*   PARAMETERS:
c*      CPU: cpu active server entity id.
c*      PRNMGR: printer manager entity id.
c*      TTY: tty active server entity id.
c*      STAT1: statistics entity id.
c*
c*   MESSAGES:
c*      TRMNT: Message to terminate the entity-instance.
c*
c*********************************************************************

        entity source(cpu,prnmgr,tty,stat1)

        local integer jobcnt,intarr
        integer trans
        real expon

        message trmnt

c*      trace 3 when .true.
c*      set interarrival rate
        intarr = 4000
        jobcnt = 0

c*      create transactions until terminated by main
10      continue
        let trans be job(cpu,prnmgr,tty,stat1)
        jobcnt = jobcnt + 1
        wait int(expon(intarr))
        if (msg .ne. trmnt) go to 10

        write(6,9000)jobcnt
9000    format(//,"Source Termination.",
     +                  /,"Number of jobs create by source = ",i6)

        ende

c*********************************************************************
c*
c*              E N T I T Y        J O B
c*
c*   FUNCTION:
c*      This is the transaction entity.
c*
c*   PARAMETERS:
c*      CPU: cpu active server entity id.
c*      PRNMGR: printer manager entity id.
c*      STAT1: statistics entity id.
c*
c*   MESSAGES:
c*      RQCOMP: Request for service completed.
c*      HAVTOK: Have been allocated resource requested.
c*
c*********************************************************************
```

```
        entity job(cpu,prnmgr,tty,stat1)

        real x,prob,lasprb,ttyprb,priarr(3),expon
        integer cpumn,prnmn,linepr,lasprn,thnkmn,arrsze,csub,prbgen
c*      printer indices for resource request array,laser probability,
c*      size of job priority array
        parameter (linepr = 1, lasprn = 2,lasprb = 0.20,arrsze = 3)
c*      means for cpu,printer service times, tty probability and think mean
        parameter(cpumn = 50,prnmn = 4000,ttyprb = 0.80,thnkmn = 5000)
        local integer prntyp(2),priort
        clocktype begclk
c*      cumulative priority probabilities for prof,grad,undergrad
        data priarr/0.20,0.50,1.0/


        message rqcomp
        message havtok

c*      trace 3 when .true.
c*      record starting time token for response stat
        call cstore(begclk,clock)

c*      set priority of transaction - ungrad = 3, grad = 2,prof = 1
        priort = prbgen(priarr,arrsze)

10      continue
c*      terminal think time
        invoke tty with reqest(myid,int(expon(thnkmn)))
        wait maxint for (msg .eq. rqcomp)

20      continue
c*      request service from computer
        invoke cpu with preqst(myid,priort,int(expon(cpumn)))

c*      wait for service complete message
        wait maxint for (msg .eq. rqcomp)

c*      branch back to tty or go on to printer
        if (rand(x) .le. ttyprb) go to 10

c*      request printer
c*      decide upon printer to use according to probability of laser
        prntyp(linepr) = 0
        prntyp(lasprn) = int(rand(x)+lasprb)
        if(prntyp(lasprn) .eq. 0) prntyp(linepr) = 1
        invoke prnmgr with preqtk(myid,priort,prntyp[2])
        wait maxint for (msg .eq. havtok)
c*      simulate printer usage
        wait int(expon(prnmn))
c*      return printer to manager
        invoke prnmgr with reltok(myid,prntyp[2])

c*      collect service stat
        invoke stat1 with insert(csub(clock,begclk))
999     continue
        ende

c***********************************************************************
c*
c*              E N T I T Y         M A I N
c*
c*      This is entity main which creates the active servers, passive
c*      resource manager, statistics entity, and source entity.
c*
c***********************************************************************
```

```
        entity main

        local integer cpu,tty,prnmgr,stat1,src
        integer initrs,srvrte,numres,resors(2),title(26),titlen
c*      set initial resources,service rate,number of resources
        parameter(initrs = 2,srvtre = 1,numres = 2,titlen=26)
        include 'common.sim'
        data title/'T','R','A','N','S','A','C','T','I','O','N',' ',
     +          'R','E','S','P','O','N','S','E',' ','T','I','M','E','S'/


        message

c*      trace 3 when .true.

        write(6,9000)
9000    format(/,"Start of Simulation."/)

c*      set length of simulation run
        simulation period 3000000
        izstim = 1000001

c*      initialize passive manager - printer - resources
        do 10, i=1,numres
           resors(i) = initrs
10      continue

c*      set up statistics entity for job response times
        let stat1 be mnstat(titlen,title)

c*      create tty
        let tty be izasdy(srvrte)

c*      create cpu activer server and printer resource manager
        let cpu be izasl2(prirty,srvrte)
        let prnmgr be iztml2(numres,resors,prirty)

c*      create jobs
        let src be source(cpu,prnmgr,tty,stat1)

c*      run for simulation period
        wait izstim

c*      dump statistics
        invoke stat1 with dump(6)
        invoke cpu with dump(6)
        invoke prnmgr with dump(6)
        invoke tty with dump(6)

c*      terminate
        invoke cpu with trmnt
        invoke prnmgr with trmnt
        invoke tty with trmnt
        invoke src with trmnt
        invoke stat1 with trmnt

        write(6,9001)
9001    format(/,"Simulation has finished.")
        ende

c*      append informs MAY compilier of needed entities
        append izasdy,izasl2,iztml2,mnstat
```

6.2.1 Results for Example Three

start of simulation.

simulation has finished.

statistical dump at simulation time 1000001.

transaction response times

the total of all values is 7072408.
the total no. of values is 264
the average value is 26789.42

statistical dump at simulation time : 1000001

System statistics for active server

Server type = priority

Service rate = 1
Number of servers = 1

response time

min	max	mean	number
0	492	52.863	1259

service time

min	max	mean	number
0	347	49.718	1259

Queue length statistics:
total jobs at server = jobs being serviced + jobs waiting

mean	max	current
0.067	3	0

System statistics :

utilization	thruput	jobs completed	jobs pre-empted
0.063	0.001	1259	0

statistical dump at simulation time : 1000001

System response time stats for token requests:

Token type: 1 initial tokens: 2

Token type: 2 initial tokens: 2

minimum response time : 0
maximum response time : 6309
number of responses : 264
mean response time : 322

Token type: 1 mean available tokens: 1

```
Token type:    2 mean available tokens:      1

System throughput      :    0.00026
mean queue length      :    0.08523
mean available tokens (all types):    3.04110

jobs still in queue :       0


statistical dump at simulation time :    1000001


System statistics for active server

 Server type = delay

 service rate =        1
 maximum number of servers =      20

 response time
        min          max              mean            number

         4          38944           4933.894          1269

 service time
        min          max              mean            number

         4          38944           4933.894          1269


 Queue length statistics:
 total jobs at server = jobs being serviced + jobs waiting
         mean                max          current

         6.207                13             10


 System statistics :

        utilization         thruput         jobs completed      jobs pre-empted

         0.050               0.001            1269                      0


source termination.
number of jobs create by source =    274
 Simulation terminated normally
 Simulation period specified:      3000000.
```

6.2.1 Code for Example Four

```
c***********************************************************************
c*
c*              E N T I T Y        S O U R C E
c*
c*   FUNCTION:
c*      This is the source entity which creates transactions according
c*      to a specified interarrival rate.
c*      Transactions are created until SOURCE is terminated.
c*
c*   PARAMETERS:
c*      CPU: cpu active server entity id.
c*      PRNMGR: printer manager entity id.
c*      TTY: tty active server entity id.
c*      STAT1: statistics entity id.
c*
c*   MESSAGES:
c*      TRMNT: Message to terminate the entity-instance.
c*
c***********************************************************************

        entity source(cpu,prnmgr,tty,stat1)

        local integer jobcnt,intarr
        integer trans
        real expon

        message trmnt

c*      set interarrival rate
        intarr = 3500
        jobcnt = 0

c*      create transactions
10      continue
        let trans be job(cpu,prnmgr,tty,stat1)
        jobcnt = jobcnt + 1
        wait int(expon(intarr))
        if (msg .ne. trmnt) go to 10

        write(6,9000)jobcnt
9000    format(//,"Source Terminated.",
     +          /,"Number of transactions created by source = ",i6)

        ende

c***********************************************************************
c*
c*              E N T I T Y        J O B
c*
c*   FUNCTION:
c*      This is the job entity.
c*
c*   PARAMETERS:
c*      CPU: cpu active server entity id.
c*      PRNMGR: printer manager entity id.
c*      TTY:   tty active server entity id.
c*      STAT1: statistics entity id.
c*
c*   MESSAGES:
c*      RQCOMP: Request for service completed.
c*      QCLOSD: Queue closed, cannot request service.
c*      HAVTOK: Have been allocated resource requested.
c*
c***********************************************************************
```

```
        entity job(cpu,prnmgr,tty,stat1)

        real x,prob,lasprb,ttyprb,priarr(3),expon
        integer cpumn,prnmn,linepr,lasprn,thnkmn,arrsze,prbgen,csub
c*      resource request array indices,laser probability
        parameter (linepr = 1, lasprn = 2,lasprb = 0.20,arrsze = 3)
c*      means for cpu,printers,think time at tty, tty probability
        parameter(cpumn = 50,prnmn = 4000,ttyprb = 0.80,thnkmn = 5000)
        local integer prntyp(2),priort
        clocktype begclk
c*      priority probability array
        data priarr/0.20,0.50,1.0/

        message rqcomp
        message qclosd
        message havtok

c*      trace 3 when .true.
c*      record starting time token for response stat
        call cstore(begclk,clock)

c*      set priority of transaction - ungrad = 3, grad = 2,prof = 1
        priort = prbgen(priarr,arrsze)

10      continue
c*      terminal think time
        invoke tty with reqest(myid,int(expon(thnkmn)))
        wait maxint for (msg .eq. rqcomp)

20      continue
c*      request service from computer
        invoke cpu with preqst(myid,priort,int(expon(cpumn)))

c*      wait for service complete message
        wait maxint for ((msg .eq. rqcomp).or. (msg .eq. qclosd))
        if (msg .eq. qclosd) go to 10

c*      branch back to tty or go on to printer

        if (rand(x) .le. ttyprb) go to 10
c*      request printer
c*      decide upon printer to use according to probability of laser
        prntyp(linepr) = 0
        prntyp(lasprn) = int(rand(x)+lasprb)
        if(prntyp(lasprn) .eq. 0) prntyp(linepr) = 1
        invoke prnmgr with preqtk(myid,priort,prntyp[2])

        wait maxint for (msg .eq. havtok)
c*      simulate printer usage
        wait int(expon(prnmn))
c*      return printer to manager
        invoke prnmgr with reltok(myid,prntyp[2])

c*      collect service stat
        invoke stat1 with insert(csub(clock,begclk))
999     continue
        ende

c*********************************************************************
c*
c*              E N T I T Y         M A I N
c*
c*      This is entity main which creates the active servers, passive
c*      resource manager, statistics entity, and source entity.
c*
c*********************************************************************
```

```
      entity main

      local integer cpu,tty,prnmgr,stat1,src
      integer initrs,srvrte,numres,resors(2),title(26),titlen,nmsrvs,quecap
c*    initial resources,service rate,number of resources,number of servers
c*    queue capacity
      parameter(initrs = 2,srvtre = 1,numres = 2,titlen=26,nmsrvs=1,quecap=5)
      include 'common.sim'
      data title/'T','R','A','N','S','A','C','T','I','O','N',' ',
     +           'R','E','S','P','O','N','S','E',' ','T','I','M','E','S'/


      message

c*    trace 3 when .true.

      write(6,9000)
9000  format(/,"Start of simulation.")
c*    set maximum simulation period, and izstim
      simulation period 3000000
      izstim = 1000010

c*    initial number of passive resource (printer) resources
      do 10, i=1,numres
         resors(i) = initrs
10    continue

c*    create response time statistics entity
      let stat1 be mnstat(titlen,title)

c*    create tty
c*    service rate 1 sim unit   = 1 msec
      let tty be izasdy(srvrte)

c*    create cpu activer server and printer resource manager
c*    service rate 1 sim unit   = 1 msec
      let cpu be izasl3(prepri,srvrte,nmsrvs,quecap)
      let prnmgr be iztml2(numres,resors,prirty)

c*    create jobs
      let src be source(cpu,prnmgr,tty,stat1)

c*    run for simulation period
      wait izstim

c*    dump statistics
      invoke stat1 with dump(6)
      invoke cpu with dump(6)
      invoke prnmgr with dump(6)
      invoke tty with dump(6)

c*    terminate
      invoke cpu with trmnt
      invoke prnmgr with trmnt
      invoke tty with trmnt
      invoke src with trmnt
      invoke stat1 with trmnt

      write(6,9001)
9001  format(/,"Simulation has finished.")
      ende

c*    append informs MAY compilier of needed entities
      append izasdy,izasl3,iztml2,mnstat
```

6.2.1 Results for Example Four

start of simulation.

simulation has finished.

statistical dump at simulation time 1000010.

transaction response times

the total of all values is 8032277.
the total no. of values is 273
the average value is 29422.26

statistical dump at simulation time : 1000010

System statistics for active server

Server type = preemptive priority

Service rate = 1
Number of servers = 1

waiting queue capacity = 5

response time

min	max	mean	number
0	420	53.160	1409

service time

min	max	mean	number
0	347	49.772	1409

Queue length statistics:
total jobs at server = jobs being serviced + jobs waiting

mean	max	current
0.075	3	0

System statistics :

utilization	thruput	jobs completed	jobs pre-empted
0.070	0.001	1409	38

statistical dump at simulation time : 1000010

System response time stats for token requests:

Token type: 1 initial tokens: 2

Token type: 2 initial tokens: 2

minimum response time : 0
maximum response time : 12086
number of responses : 273
mean response time : 491

Token type: 1 mean available tokens: 1

```
Token type:    2 mean available tokens:      1

System throughput       :    0.00027
mean queue length      :   0.13431
mean available tokens (all types):    2.93317

jobs still in queue :      0


statistical dump at simulation time :    1000010


System statistics for active server

Server type = delay

service rate =       1
maximum number of servers =      20

response time
        min          max              mean            number

         1         38944          4931.275            1416

service time
        min          max              mean            number

         1         38944          4931.275            1416


Queue length statistics:
total jobs at server = jobs being serviced + jobs waiting
         mean              max        current

         6.949              15            7


System statistics :

        utilization       thruput        jobs completed      jobs pre-empted

         0.050             0.001           1416                       0

source terminated.
number of transactions created by source =    280
Simulation terminated normally
Simulation period specified:       3000000.
```

6.2.1 Code for Example Five

```
c*      RQCOMP: Request for service completed.
c*      QCLOSD: Queue closed, cannot request service.
c*      HAVTOK: Have been allocated resource requested.
c*
c*********************************************************************

        entity job(cpu,prnmgr,tty,disk1,disk2,stat1)

        integer cpumn,prnmn,thnkmn,dskmn,pbasze,pbisze
c*      means for cpu,printers,think time,disks
        parameter (cpumn = 50,prnmn= 4000,thnkmn = 5000,dskmn= 20)
        real lasprb,dsk1pb,dsk2pb,prnprb,x,expon,prbarr(4),priarr(3)
c*      laser probability,probability array sizes
        parameter(lasprb = .20,pbasze=4,pbisze=3)
        integer linepr,lasprn,ungrad,grad,prof,branch,prbgen,csub
c*      resource request array indices,priority assignments
        parameter (linepr = 1, lasprn = 2,ungrad = 3, grad = 2,prof = 1)
        local integer prntyp(2),priort
        clocktype begclk
c*      cumulative probability array for branching after cpu
        data prbarr/0.20,0.30,0.40,1.00/
c*      cumulative probability array for priority assignment
        data priarr/0.20,0.50,1.00/

        message rqcomp
        message havtok
        message qclosd

c*      trace 3 when .true.

c*      record starting time token for response stat
        call cstore(begclk,clock)

c*      set priority of transaction
        priort = prbgen(priarr,pbisze)

10      continue
c*      terminal think time
        invoke tty with reqest(myid,int(expon(thnkmn)))

        wait maxint for (msg .eq. rqcomp)

20      continue
c*      request service from computer
        invoke cpu with preqst(myid,priort,int(expon(cpumn)))
c*      wait for service complete message
        wait maxint for ((msg .eq. rqcomp) .or. (msg .eq. qclosd))

c*      branch after cpu
c*      printer=1, disk1=2, disk2=3, tty=4
        branch = prbgen(prbarr,pbasze)
        go to (30,40,50,10)branch

30      continue
c*      request printer
c*      decide upon printer to use according to probability of lazer
        prntyp(linepr) = 0
        prntyp(lasprn) = int(rand(x)+lasprb)
        if (prntyp(lasprn) .eq. 0 ) prntyp(linepr) = 1
        invoke prnmgr with preqtk(myid,priort,prntyp[2])
        wait maxint for (msg .eq. havtok)
c*      simulate printer usage
        wait int(expon(prnmn))
        invoke prnmgr with reltok(myid,prntyp[2])
        go to 998
```

```
40      continue
        invoke disk1 with reqest(myid,int(expon(dskmn)))
        wait maxint for (msg .eq. rqcomp)
c*      return to cpu
        go to 20

50      continue
        invoke disk2 with reqest(myid,int(expon(dskmn)))
        wait maxint for (msg .eq. rqcomp)
c*      return to cpu
        go to 20

998     continue
c*      collect response time stats
        invoke stat1 with insert(csub(clock,begclk))
999     continue
        ende


c***********************************************************************
c*
c*             E N T I T Y        M A I N
c*
c*      This is entity main which creates the active servers, passive
c*      resource manager, statistics entity, and source entity.
c*
c**********************************************************************
        entity main

        integer nmres,resors(2),nmsrvs,quecap,titlen
        local integer cpu,prnmgr,tty,disk1,disk2,stat1,src
        integer srvrte,initrs,title(26)
c*      service rate,initial resources,number of resources,number of
c*      servers, queue capacity
        parameter(srvtre = 1,initrs = 2,nmres = 2,nmsrvs = 2,quecap = 5)
        parameter(titlen = 26)
        include 'common.sim'
        data title/'T','R','A','N','S','A','C','T','I','O','N',' ',
     +        'R','E','S','P','O','N','S','E',' ','T','I','M','E','S'/

        message

c*      trace 3 when .true.

        write(6,9000)
9000    format("Start of simulation.")

c*      set maximum simulation period
        simulation period 2500000
        izstim = 850001

c*      initial number of passive resource (printer) resources
        do 10, i=1,nmres
           resors(i) = initrs
10      continue

c*      set up statistics entity for transaction response times
c*      stat1 will be for simple recording of the mean response time
        let stat1 be mnstat(titlen,title)

c*      create tty
        let tty be izasdy(srvrte)
c*      create cpu activer server and printer resource manager
        let cpu be izasl3(prepri,srvrte,nmsrvs,quecap)
        let prnmgr be iztml2(nmres,resors,pirty)
c*      create disks
```

```
        let disk1 be izasl2(fcfs,srvrte)
        let disk2 be izasl2(fcfs,srvrte)
c*      create jobs
        let src be source(cpu,prnmgr,tty,disk1,disk2,stat1)

        wait izstim

c*      dump statistics
        invoke stat1 with dump(6)
        invoke cpu with dump(6)
        invoke prnmgr with dump(6)
        invoke tty with dump(6)
        invoke disk1 with dump(6)
        invoke disk2 with dump(6)

c*      terminate
        invoke cpu with trmnt
        invoke prnmgr with trmnt
        invoke tty with trmnt
        invoke disk1 with trmnt
        invoke disk2 with trmnt
        invoke src with trmnt
        invoke stat1 with trmnt

        write(6,9001)
9001    format(/,"Simulation has finished")
        ende

c*      append informs MAY compilier of entities needed
        append iztml2,izasdy,izasl2,izasl3,mnstat
```

```
start of simulation.

simulation has finished


 statistical dump at simulation time       850001.

                                   transaction response times
 the total of all values is        791502.
 the total no. of values is            33
 the average value is       23984.91


 statistical dump at simulation time :     850001



System statistics for active server

 Server type = preemptive priority

 Service rate =       1
 Number of servers =       2

 waiting queue capacity =       5

 response time
        min          max              mean            number

         0            199             45.744            172

 service time
        min          max              mean            number

         0            199             45.744            172


 Queue length statistics:
 total jobs at server = jobs being serviced + jobs waiting
         mean                max        current

         0.009                 2             0


 System statistics :

        utilization       thruput        jobs completed      jobs pre-empted

         0.005              0.000            172                        0

 statistical dump at simulation time :     850001


 System response time stats for token requests:

 Token type:      1 initial tokens:      2

 Token type:      2 initial tokens:      2

 minimum response time :       0
 maximum response time :       0
 number of responses   :      33
 mean response time    :       0

 Token type:     1 mean available tokens:      1
```

6.2.1 Results for Example Five

```
c*********************************************************************
c*
c*              E N T I T Y        S O U R C E
c*
c*   FUNCTION:
c*      This is the source entity which creates transactions according
c*      to a specified interarrival rate.
c*      Transactions are created until SOURCE is terminated.
c*
c*   PARAMETERS:
c*      CPU: cpu active server entity id.
c*      PRNMGR: printer manager entity id.
c*      TTY: tty active server entity id.
c*      DISK1: disk1 active server entity id.
c*      DISK2: disk2 active server entity id.
c*      STAT1: statistics entity id.
c*
c*   MESSAGES:
c*      TRMNT: Message to terminate the entity-instance.
c*
c*********************************************************************

        entity source(cpu,prnmgr,tty,disk1,disk2,stat1)

        local integer jobcnt,intarr
        integer trans
        real expon

        message trmnt

c*      trace 3 when .true.

c*      set interarrival rate
        intarr = 25000
        jobcnt = 0

c*      create transactions
10      continue
        let trans be job(cpu,prnmgr,tty,disk1,disk2,stat1)
        jobcnt = jobcnt + 1
        wait int(expon(intarr))
        if (msg .ne. trmnt) go to 10

        write(6,9000)jobcnt
9000    format(/,"Source Termination.",
     +         /,"Number of transactions created by source = ",i6)

        ende

c*********************************************************************
c*
c*              E N T I T Y        J O B
c*
c*   FUNCTION:
c*      This is the job entity.
c*
c*   PARAMETERS:
c*      CPU: cpu active server entity id.
c*      PRNMGR: printer manager entity id.
c*      TTY:   tty active server entity id.
c*      DISK1: disk1 active server entity id.
c*      DISK2: disk2 active server entity id.
c*      STAT1: statistics entity id.
c*
c*   MESSAGES:
```

```
Token type:    2 mean available tokens:      1

System throughput       :    0.00004
mean queue length      :    0.
mean available tokens (all types):    3.82239

jobs still in queue :      0


statistical dump at simulation time :     850001


System statistics for active server

Server type = delay

service rate =       1
maximum number of servers =      20

response time
        min          max              mean            number

        53          23053           4612.314           137

service time
        min          max              mean            number

        53          23053           4612.314           137


Queue length statistics:
total jobs at server = jobs being serviced + jobs waiting
         mean                max        current

         0.743                4            0


System statistics :

        utilization       thruput        jobs completed     jobs pre-empted

         0.026              0.000            137                       0


statistical dump at simulation time :     850001


System statistics for active server

Server type = fcfs

Service rate =       1
Number of servers =       1

response time
        min          max              mean            number

         0             77             24.375            16

service time
        min          max              mean            number

         0             77             24.375            16
```

Queue length statistics:
total jobs at server = jobs being serviced + jobs waiting

mean	max	current
0.000	1	0

System statistics :

utilization	thruput	jobs completed	jobs pre-empted
0.000	0.000	16	0

statistical dump at simulation time : 850001

System statistics for active server

Server type = fcfs

Service rate = 1
Number of servers = 1

response time

min	max	mean	number
2	62	20.632	19

service time

min	max	mean	number
2	62	20.632	19

Queue length statistics:
total jobs at server = jobs being serviced + jobs waiting

mean	max	current
0.000	1	0

System statistics :

utilization	thruput	jobs completed	jobs pre-empted
0.000	0.000	19	0

source termination.
number of transactions created by source = 33
No active entities present.
Simulation terminated at time: 850001.