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Management of Communications in Distributed Systems with Time Constraints

Douglas M. Wells
The Open Group
<d.wells@opengroup.org>

A[n Application] System

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- A system is [from Merriam-Webster]
  - 1) a regularly interacting or interdependent group of items forming a unified whole: as
    - d) a group of devices or artificial objects or an organization forming a network esp. for distributing something or serving a common purpose
- A[n application] system is a set of resources organized to effect organization goals

Resource Management

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- Management is [from Merriam-Webster]
  - 2) judicious use of means to accomplish an end
- Resource management is the judicious use of resources to effect organization goals
- A resource manager attempts to maximize the value produced by consuming available resources within a system

Distributed Systems

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- A distributed application [system]
  - Requires processing resources on each of several nodes
  - Requires communication resources between those nodes
- Components within a distributed system
  - Cannot communicate in zero time
  - Are often in different failure domains

Resource Management in Distributed Systems

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- Resource management decisions occur at
  - Design time
  - Configuration time
  - Run time (operator control)
  - Run time (self-adaptivity)
- Resource management in distributed systems can be centralized or distributed
- A resource manager generates a **schedule** of resource allocations and assigns resource **reservations**

RM Example #1

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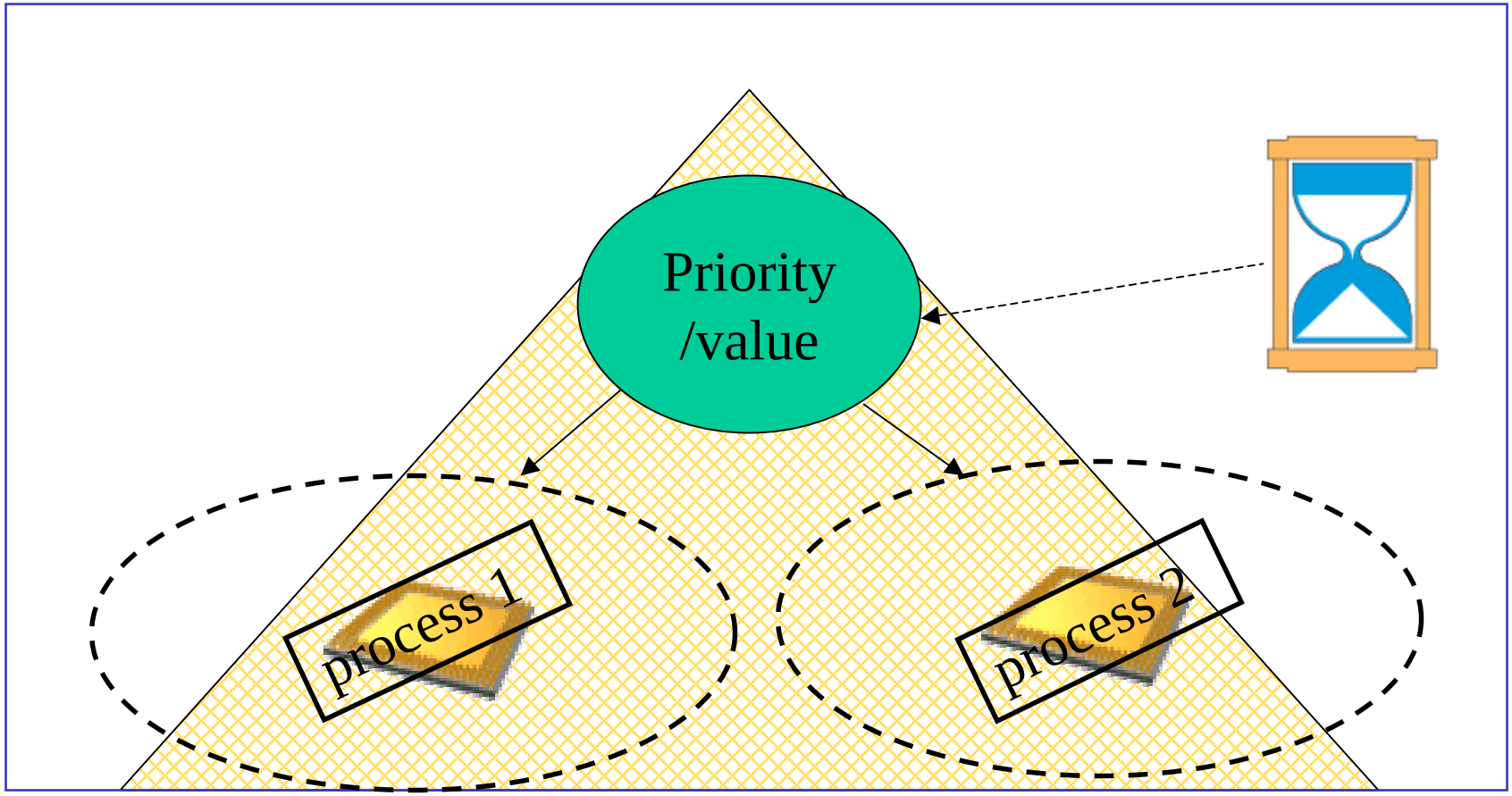
Operating System CPU Scheduler



RM Example (ii)

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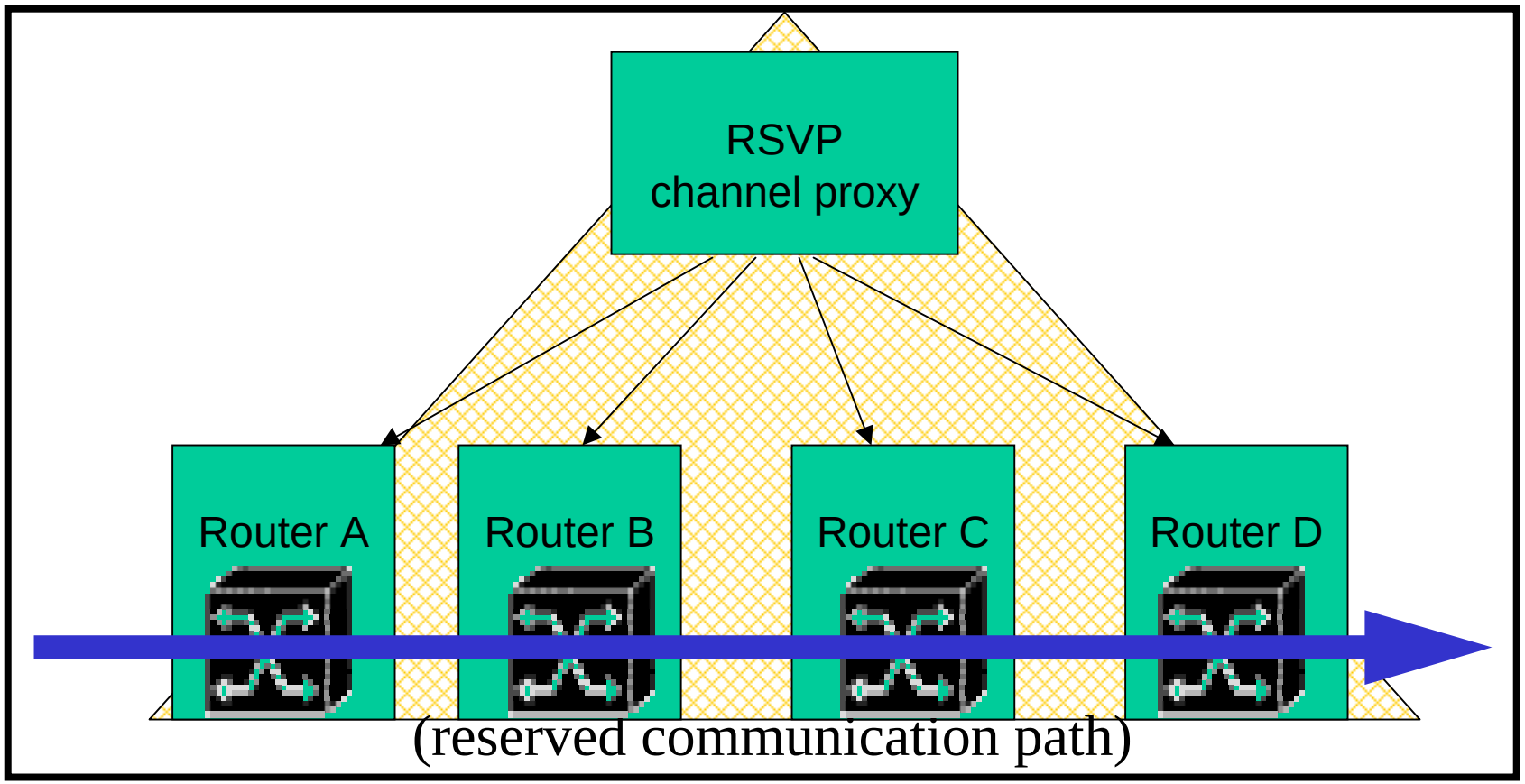
RSVP Internet Link



RM Example (iii)

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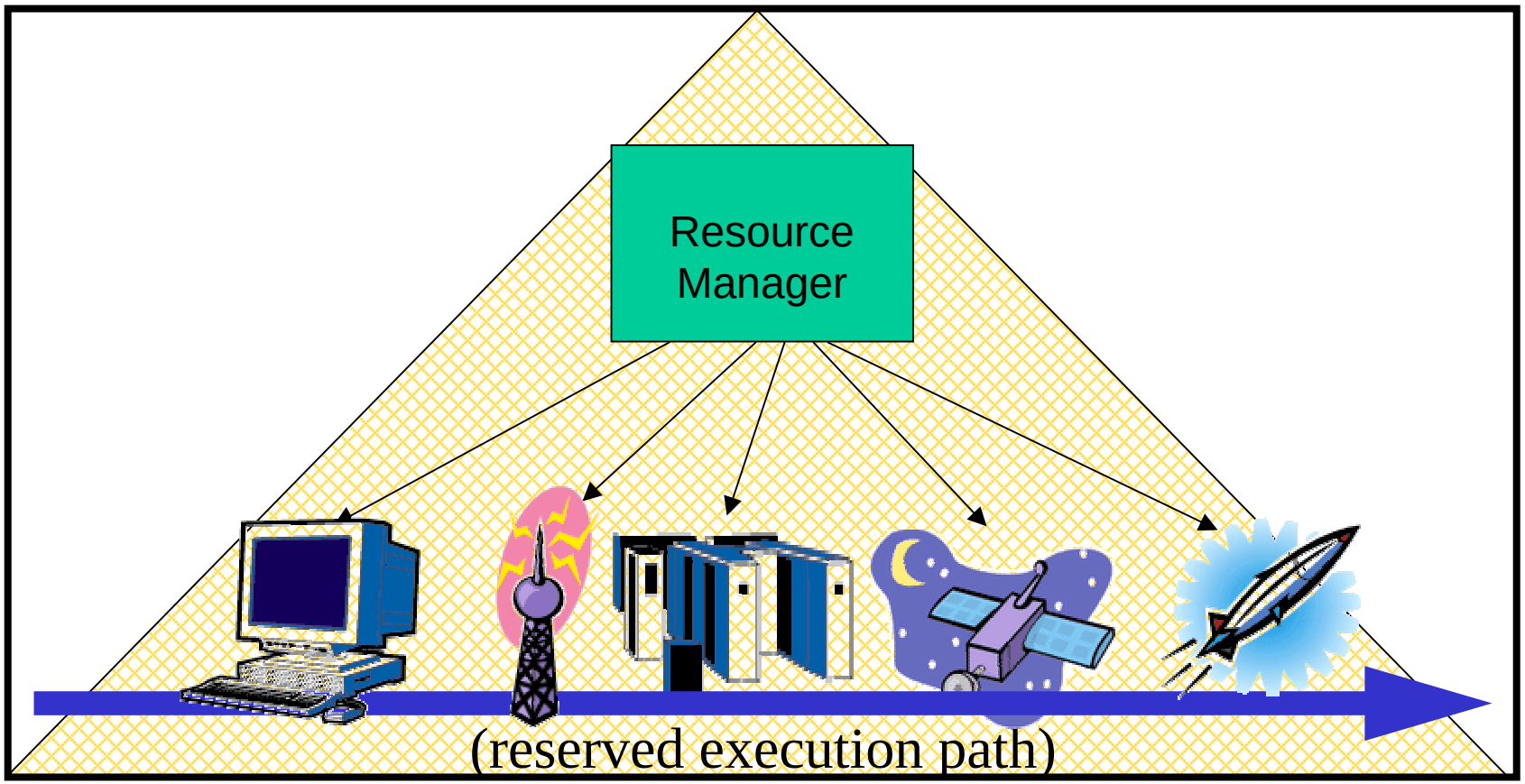
End-to-End Execution Path



The Resource Management Process (i)

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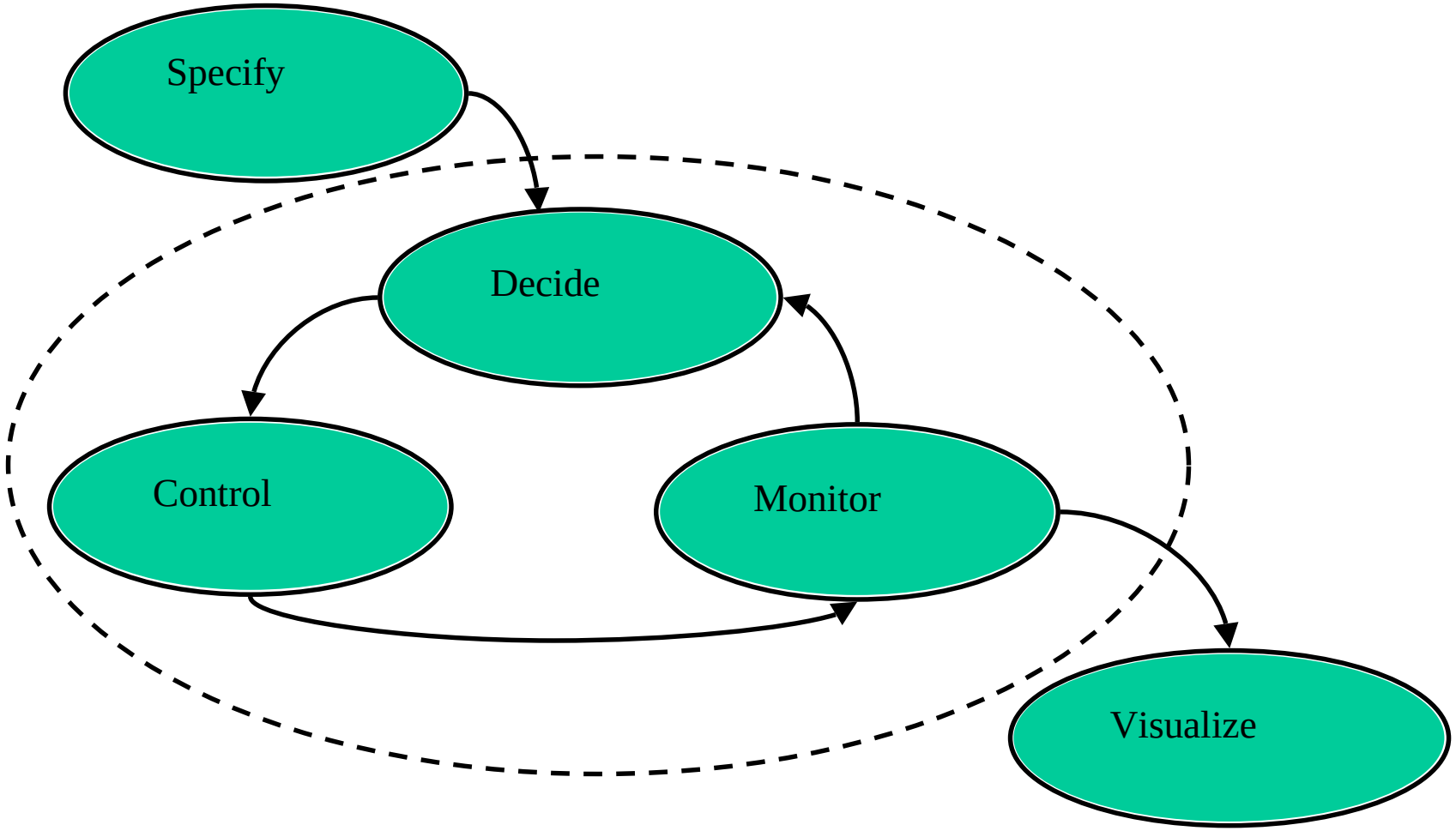
- A Control Theory Viewpoint



The Resource Management Process (ii)

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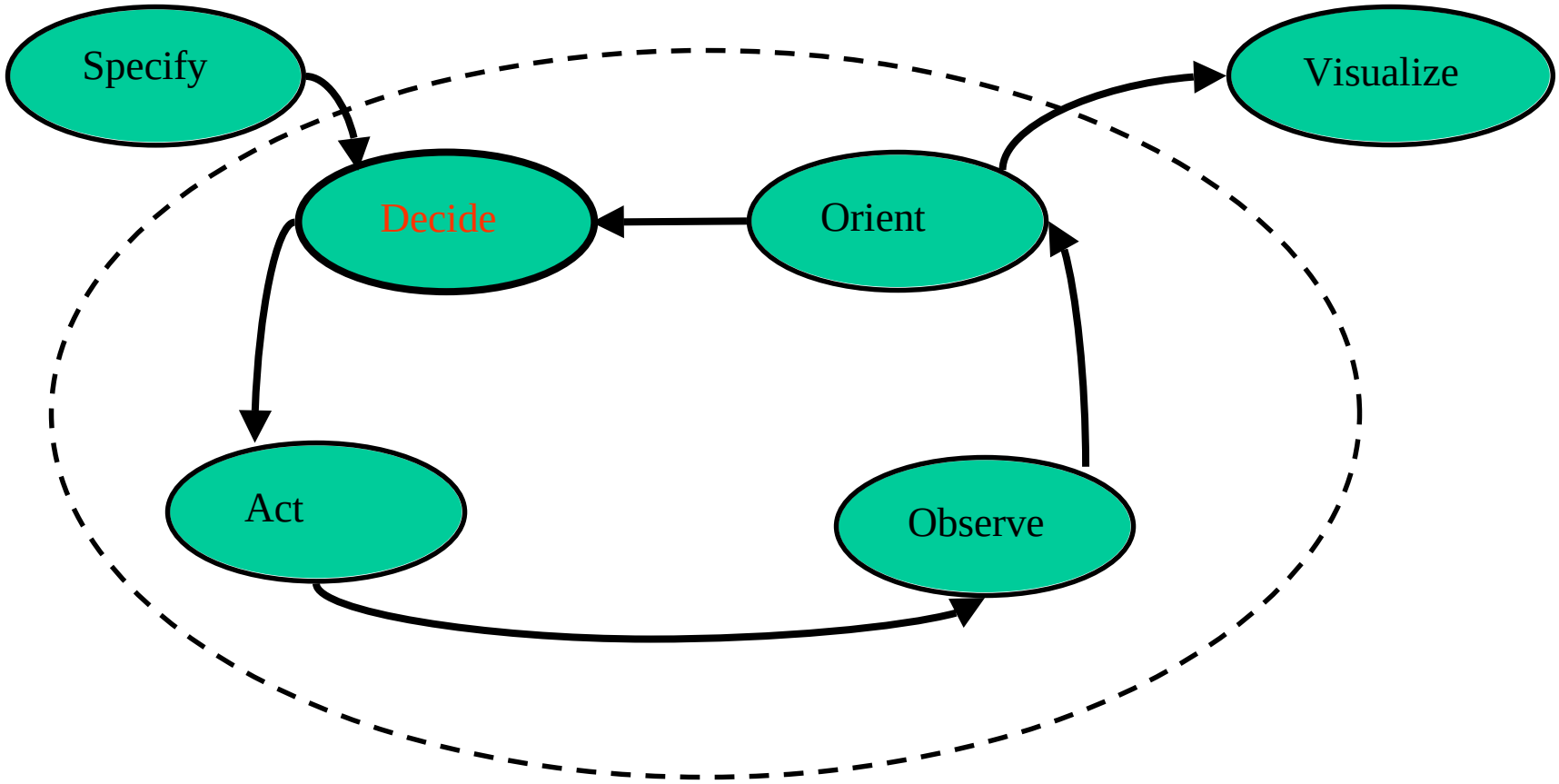
- A Boyd Cycle Viewpoint



Attributes of Resources

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- Resources are enumerated, but extensible
  - CPU usage
  - Bandwidth
- “Resources” can be abstract
  - End-to-end path
  - Tracks
  - Track clusters

Attributes of Resources (cont'd)

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- Resources must be manageable for resource management to function
  - Performance metric(s) must exist
  - Performance must be controllable
    - Directly, e.g., time/frequency multiplexing
    - Indirectly, e.g., processor priorities
- A resource is worth managing only if it is valuable—and scarce

Time–a Special Kind of Resource

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- Many resources derive from time
  - CPU cycles, transmission capacity, data storage
- Access to many resources is limited by time
  - Disk access, Ethernet cable length limits
- Many resources are serially reusable
- Time flies like an arrow—relentlessly
- Primarily incorporated via reservations, which include a time period of use

Time Constraints

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- A time constraint is a time-based performance metric for the occurrence of
  - a required (non-unique) state change
  - within specified bounds
- There are both beginning and ending states, and there may be additional intermediate states
- Achieving a time constraint requires that a (non-unique) set of actions occur
- Effecting the set of actions requires that a (non-unique) set of resources be applied

Managing Resource Usage with Time Constraints (i)

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- From a previous slide:
  - *Resources must be manageable for resource management to function*
    - *Performance metric(s) must exist*
    - *Performance must be controllable*
- A time constraint is a performance metric
- How to control performance?
  - —by managing allocation and assignment of resource reservations

Managing Time-Constrained Resource Usage (ii)

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- To achieve a time constraint, a resource manager must understand
  - The beginning and end states
  - The set of resources required to perform the associated state change
- For admission control (in the case of resource conflict), a resource manager must maintain an association between
  - the state transition, and
  - the set of resources that is needed to perform the state change

Managing Time-Constrained Resource Usage (iii)

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- This association is a name in a namespace
- Let us call this association an activity (a.k.a., computation, path, task, thread, job)
- Examples of activities include
  - Thread execution
  - DBMS transactions
  - Message delivery
- A time constraint can be associated with an activity
- More importantly, different time constraints can be associated with different activities

Example: Time-Constrained Thread Execution

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- Consider thread execution within an OS
- Activity name = thread identifier (POSIX tid)
- Consider a time constraint for a thread
  - Initial state: PC at procedure P1 label *L1*
  - Final state: PC at procedure *P2* label *L2*
  - Bounds: less than 2 msec between states
  - Resources required: CPU, memory, disk I/O
- Resource management mechanisms
  - Priority
  - Deadline
  - Benefit/value functions

Example: Time-Constrained Transaction (i)

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- Consider a DBMS transaction connection
- Activity name = DBMS transaction id (often hidden by languages)
- Possible time constraint
  - Initial state: consistent DBMS state *S1*
  - Final state: consistent DBMS state *S2 (or S1!)*
  - Bounds: less than 1 sec between states
  - Resources required
    - CPU, memory
    - Disk I/O, stable storage space
    - Potential resources for roll-back!

Example: Time-Constrained TCP Connection (i)

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- Consider data delivery via a TCP connection
- Activity name = TCP connection name
- Possible time constraint for a data byte
  - Initial state: transmission by sending
  - Final state: acceptance by receiver
  - Bounds: less than 2 msec between states
  - Resources required
    - Transmitter, receiver (e.g., buffers, CPU)
    - Intermediate routers (e.g., buffers, CPU)
    - Communication channel time slot

Example: Time-Constrained TCP Connection (ii)

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- Let's examine the admission control process
- Resource management mechanisms
  - Use of dedicated network
  - Use of message packet priority
  - Allocation of RSVP channel
  - Use of diff-serv techniques

Example: Time-Constrained TCP Connection (iii)

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- Let's reexamine admission control from the viewpoint of an intermediate router
- How can a resource manager within a router assign resources to ensure adherence to time constraints?
  - Use of dedicated network
  - Use of message packet priority
  - X Allocation of RSVP channel
  - ? Use of diff-serv techniques

Example: Time-Constrained TCP Connection (iii)

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- Now consider admission control from the viewpoint of a router at the receiving end
- Assumptions:
  - Use of RSVP channels
  - Two channels exist concurrently, each with end-to-end time constraint of 5 msec.
  - Two packets arrive simultaneously
    - Packet 1 has existed for 4.9 msecs.
    - Packet 2 has existed for 2 msecs
- How do we get the router to know that it should process packet 1 first?

Topic for Discussion

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- The system engineer has knowledge of design goals, structure, limitations, etc.
- The domain engineer has knowledge of the general application environment.
- The operator/user has knowledge of the system goals as deployed and employed.
- Many system constraints are environmental and can't be known *a priori*
- How do we fuse all of this knowledge into a self-adaptive system so that it can make effective and efficient decisions at run time?
- More particularly, how do we do that for asynchronous systems?