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Uncertain Requirements

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Requirements in Systems Engineering

Some High-level requirements made hard initially

- More detailed requirements made hard over time
  - All Requirements must eventually be made hard
    - Verification assesses compliance of physical design with requirements
      - Validation assesses whether requirements were sufficient

Hard requirements often change with new information

- About the environment in which system will be used,
- About how it will be used in that environment
- About how the stakeholder expects it to perform when used in the environment

Proposed Solution: Set-based Requirements

- There is uncertainty in the Maximum capability stakeholders will need when they actually use the system across its full lifecycle

- Uncertainty can be described by intervals

  - Lenient (sunny day) Bound:
    - On the maximum capability required
    - Negligible chance stakeholder would be satisfied over the life of the product/service with anything less than this capability
  - Stringent (rainy day) Bound
    - On the maximum capability required
    - Negligible chance stakeholder would need more capability to be satisfied over the life of the product/service

Comparison with current definition of requirements

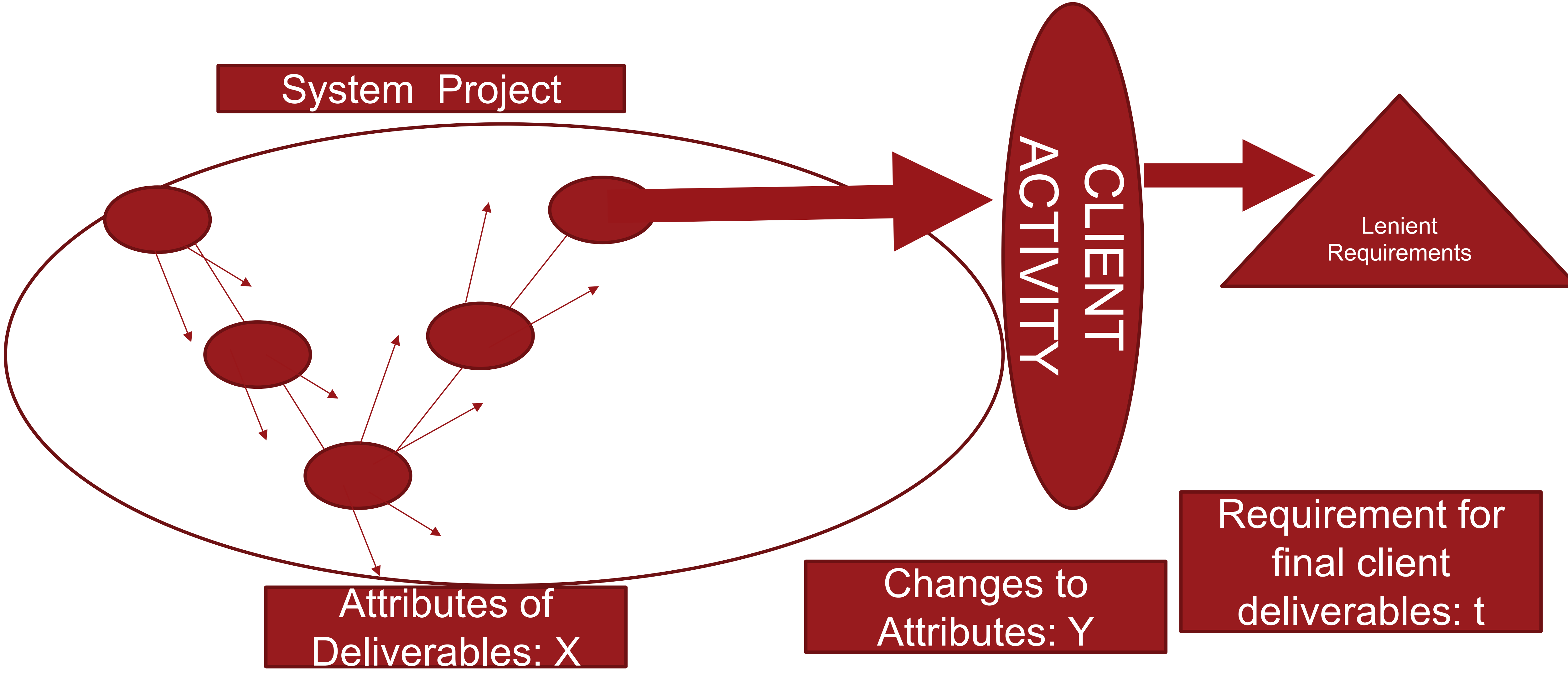
- Current definition of requirements
  - Threshold: Any design with less capability is inadequate
  - Objective: Negligible value to have more capability than objective
  - Designs closer to objective (and further from threshold) are more desirable
- Comparison from set-based requirements:
  - Lenient bound
    - Like threshold, stakeholder will not be satisfied with less capability than the lenient bound. But new information might make this bound more demanding
  - Stringent bound
    - Like objective, stakeholder attaches negligible value to having more capability than the stringent bound. But new information might make the stringent bound less demanding.
  - Designs closer to the stringent bound (and further from lenient bound) are more robust to new information
- Gap between upper and lower bound may decrease because of new information
  - Negligible chance the gap with increase

Incorporating set-based requirements in design

- Most design processes require hard requirements
    - How do we handle set-based requirements?

- First we consider a special case where the solution is obvious
    - The project manager produces project deliverables for a client
    - The client then uses these deliverables in their own activity to produce their own client deliverables
    - These deliverables must then meet hard requirements

When engineering is part of a Supply Chain



Properties of a traditional supply chain

- The end-customer places an order for ten units of product at a retailer
  - If the retailer has ten units in inventory, the retailer fills the order
    - Otherwise the retailer loses sales
    - The retailer places an order with the wholesaler for enough units to refill the inventory
  - The wholesaler fills the order if it has enough inventory
    - The wholesaler places an order with the factory to produce more units to replenish their inventory
    - To produce these units, the factory needs its suppliers to provide it with raw materials
    - The factory places orders with each of its first tier suppliers to provide raw materials
      - If the suppliers have enough units in inventory, they sell them
      - Otherwise, they must produce more units
        - The suppliers place orders with the second tier suppliers for input materials, etc.

The Whiplash effect in supply chains

- Small changes in what the end-customer requires (orders) are magnified into very large changes for suppliers at lower tiers of the supply chain because
    - each supplier focuses on what their immediate customer orders
    - Each supplier hedges against uncertainty by holding more inventory (capability) than they expect their customer to require
    - When their customer's requirements (order) changes, they must make an even large change in order to have the reserve capability (inventory) they desire
    - This small changes in what the ultimate customer wants causes tremendous churn in the supply chain
- To eliminate the whiplash effect,
    - Each supplier must focus on the demand from the end-customer
    - They must also recognize the process by which that demand gets translated into demand for what the supplier provides

The Whiplash effect in Design Projects

- Client seems to maximize probability X+T is less than t
  - So client wishes to set the project requirements so that X is less than t-T
    - There is no guaranteed way of doing this since T is uncertain and what the project can realistically deliver, X, is also uncertain.
    - So requirements x must be set reflecting a reasonable balance between X and T
- Client then learns that their activity will take longer than expected
  - T changes to T*
  - Reasonable balance changes from x to x*
  - Requirements change
    - May continue to change as client gets more information about their activity
    - Note that making the client think harder about what they want cannot reduce uncertainty coming from the environment

Applying the solution to the Whiplash Effect

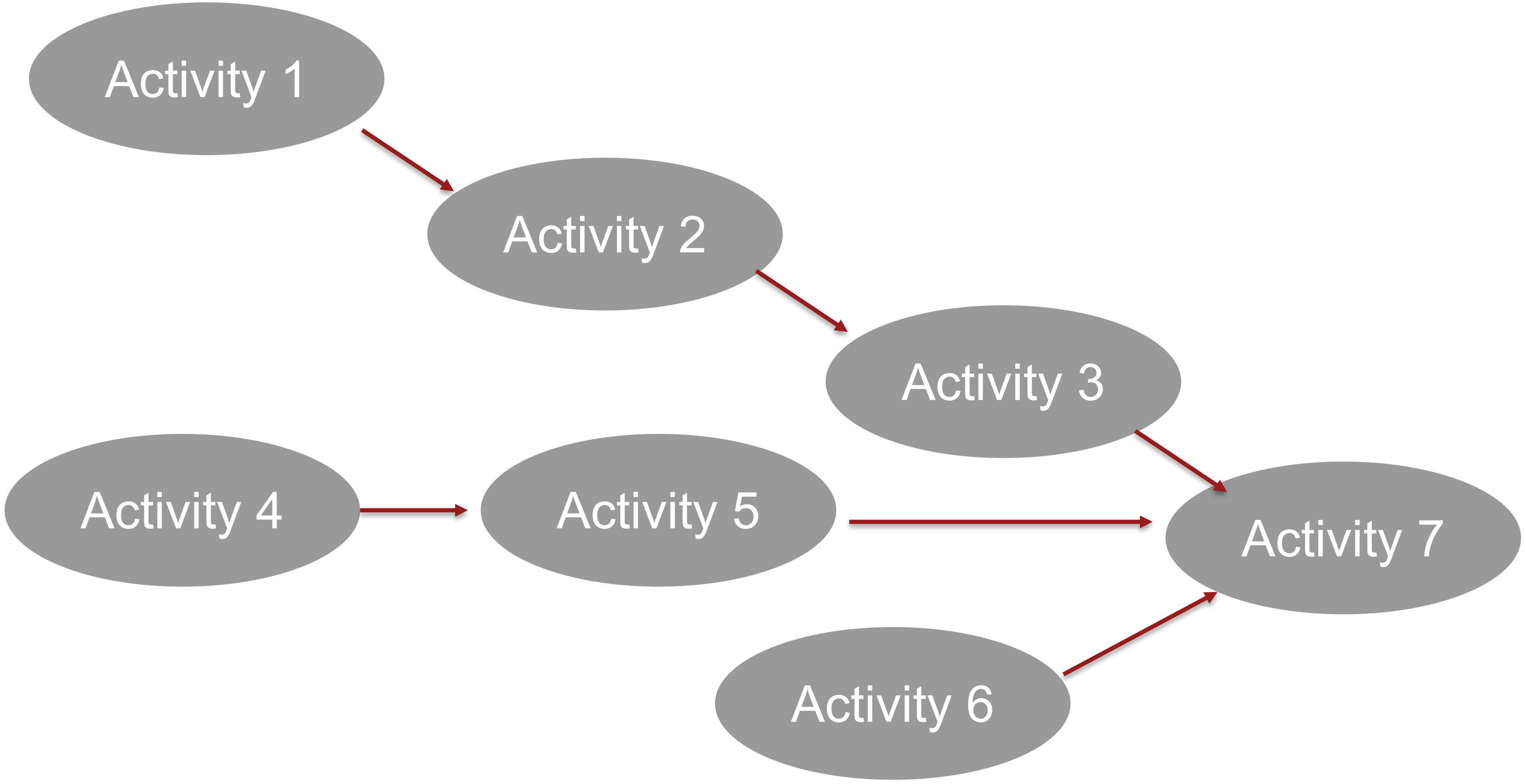
- Supply chain theory has solved this problem
  - Project Manager must focus on ultimate requirement t
  - Like the client, the manager will maximize probability X+T < t
    - However the manager only can impact X, the attributes of the project deliverables
    - So the uncertainty, T, is simply added on to all the other physical uncertainties associated with the deliverables

- To extend this solution to the case where the manager is not part of a supply chain:
  - Define a hard requirement, t, using the optimistic bound
  - Define requirement uncertainty, T, as the uncertain amount by which the optimistic bound differs from the actual (but uncertain) maximum capability needed
    - Add this requirement uncertainty to the physical uncertainty, X, about the attributes of the deliverables created in the design process

Estimating Value of set-based requirements

- Consider simple case with only one requirement uncertainty
  - The project deadline
  - optimistic bound is the least demanding deadline --- which becomes the hard requirement
  - pessimistic bound is the most demanding deadline
  - Deadline uncertainty is the gap between the optimistic and pessimistic bound deadline

Simulation focuses on following project network



Simulation

- Randomly generate
  - an uncertain deadline
  - uncertain completion times for each activity with different means but the same standard deviation S
- To assess how deadline uncertainty information improves decision making
  - Focus on the decision to crash different activities by adding more personnel and resources to the activity
  - Determine best crashing decision for manager who
    - Is unaware of the uncertainty in the project deadline
    - Is aware of the degree of uncertainty in the project deadline
- Compare the % on-time completion rate
  - For manager who makes crashing decision while recognizes uncertainty in the deadline
    - For manager who uses ISO standard PERT rule for making crashing decisions
    - For manager who uses formal optimization to make crashing decisions
  - For manager who makes crashing rule ignores uncertainty in the deadline
    - For manager who uses ISO standard PERT rule for making crashing decisions
    - For manager who uses formal optimization to make crashing decisions

Results

S	No Crashing	PERT with fixed deadline	Optimization with fixed deadline	PERT with uncertain deadline	Optimization with uncertain deadline
0.0	74.21%	74.21%	74.21%	91.24%	94.49%
0.5	72.1%	85.47%	77.82%	88.29%	91.07%
1.0	66.18%	82.81%	81.29%	84.65%	87.91%
2.0	53.83%	77.25%	81.49%	77.29%	81.50%

20% Improvements in considering uncertainty given no uncertainty in activities

Amount of improvement decreases when the uncertainty in the activities increases

- Because the potential gain from crashing diminishes with a less predictable network

Conclusions

- Introduce simple extension of familiar threshold/objective representation of requirements
- Modification allows for early representation of requirement uncertainty
  - Previously, we delayed specifying requirements until they could be made hard
    - Problem: substantial requirement change shows that many requirements cannot become hard
    - Secondary problem: no information on requirements that are close to being made hard
  - Proposal: specify requirements early but allow range between bounds on those requirements to tighten with information as time passes.
    - Provides earlier information on the degree of uncertainty in the capabilities required by the stakeholders
    - Allows decision making to be made even when for requirements that never become hard
- Simulation
  - Focused on case when only uncertain requirement is the deadline
  - Examined the quality of the decisions managers made both with information on requirement uncertainty and without that information
  - Demonstrated substantial improvement in decision quality as long as the uncertainty in project deliverables was not large

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