A Framework for Planning in Continuous-time Stochastic Domains

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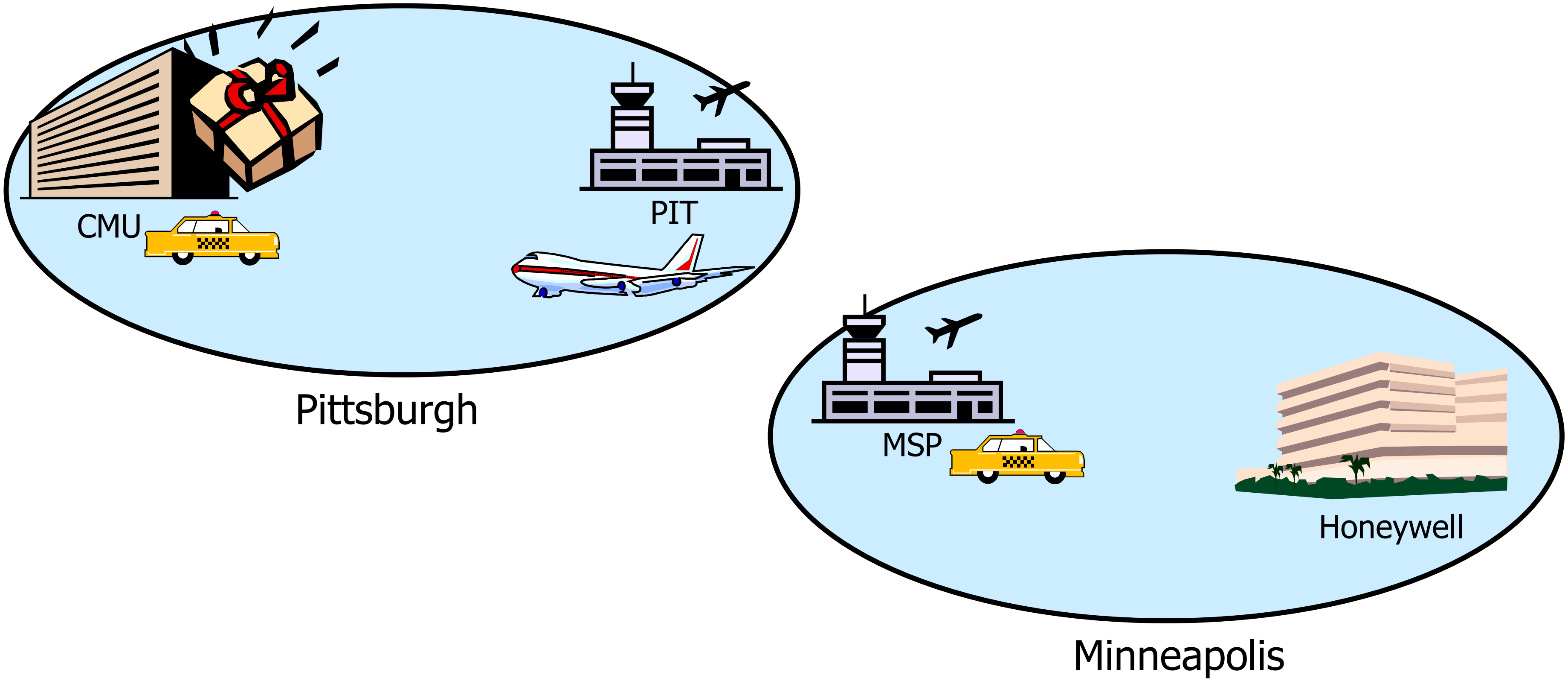
Introduction

- Policy generation for complex domains
  - Uncertainty in outcome and timing of actions and events
  - Time as a continuous quantity
  - Concurrency
- Rich goal formalism
  - Achievement, maintenance, prevention
  - Deadlines

Motivating Example

- Deliver package from CMU to Honeywell



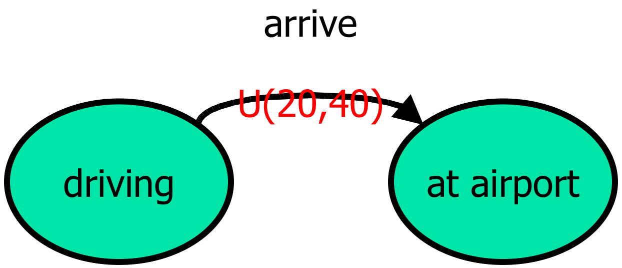
Elements of Uncertainty

- Uncertain duration of flight and taxi ride
- Plane can get full without reservation
- Taxi might not be at airport when arriving in Minneapolis
- Package can get lost at airports

Modeling Uncertainty

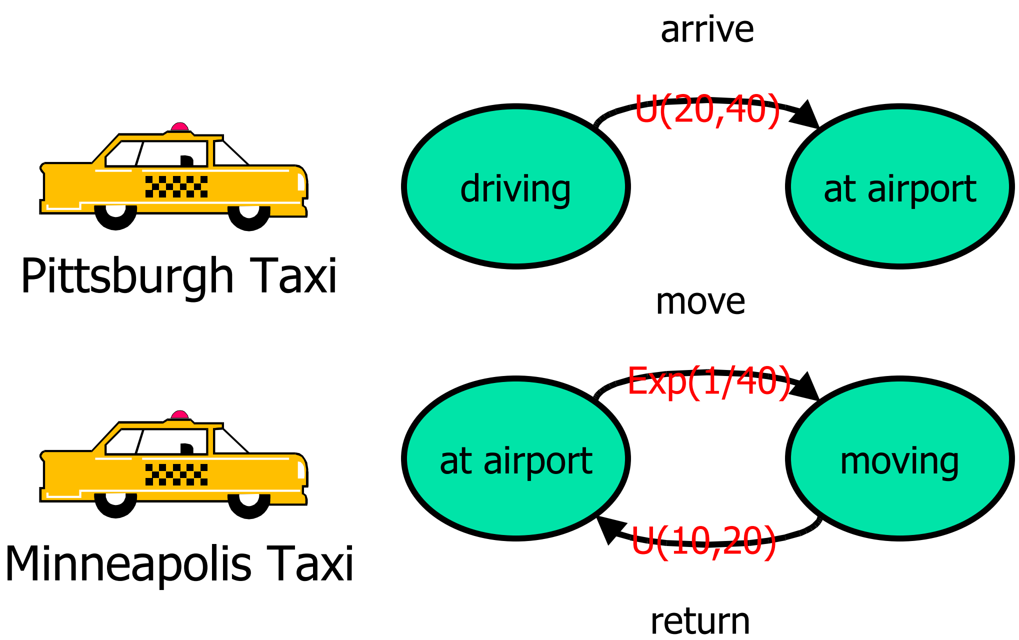
- Associate a delay distribution F(t) with each action/event a
- F(t) is the cumulative distribution function for the delay from when a is enabled until it triggers

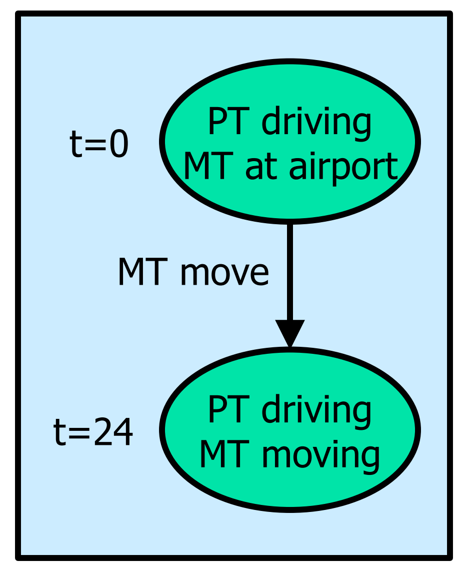
Pittsburgh Taxi



Concurrency

- Concurrent semi-Markov processes





Generalized semi-Markov process

Rich Goal Formalism

- Goals specified as CSL formulae
  - $\phi ::= \mathrm{true} \mid a \mid \phi \wedge \phi \mid \neg\phi \mid \mathrm{Pr}_{\geq \theta}(\rho)$
  - $\rho ::= \phi\ \mathrm{U}^{\leq t}\ \phi \mid \Diamond^{\leq t}\ \phi \mid \Box^{\leq t}\ \phi$

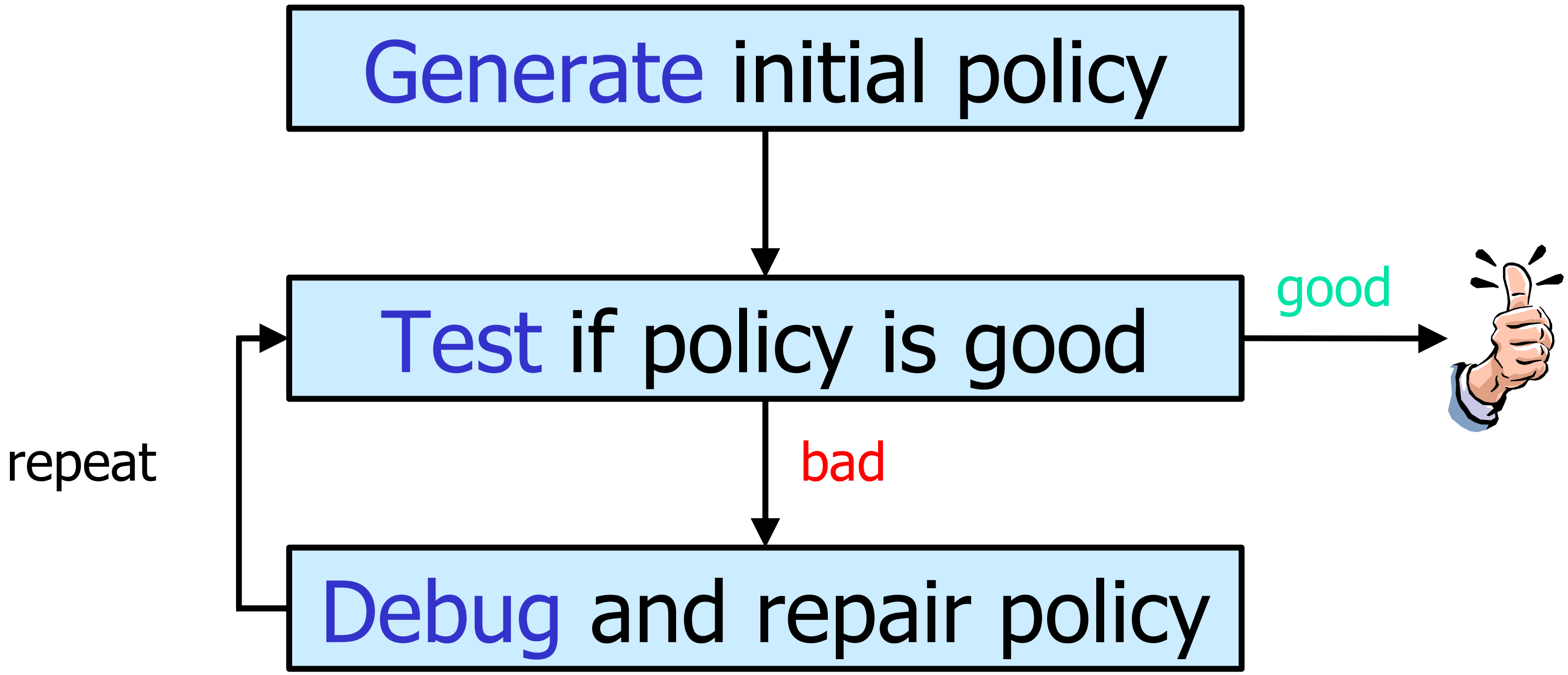
Goal for Motivating Example

- Probability at least 0.9 that the package reaches Honeywell within 300 minutes without getting lost on the way
  - $Pr_{\geq 0.9}(\neg \text{pkg lost } U^{\leq 300} \text{ pkg@Honeywell})$

Problem Specification

- Given:
  - Complex domain model
    - Stochastic discrete event system
  - Initial state
  - Probabilistic temporally extended goal
    - CSL formula
- Wanted:
  - Policy satisfying goal formula in initial state

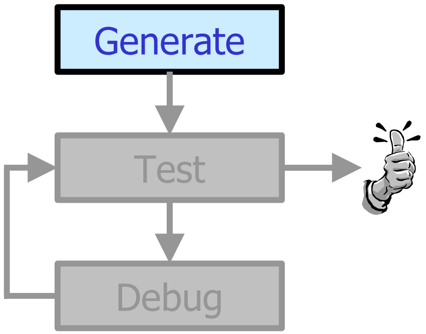
Generate, Test and Debug [Simmons 88]



Generate

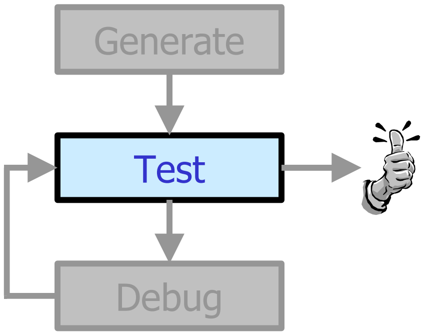
- Ways of generating initial policy
  - Generate policy for relaxed problem
  - Use existing policy for similar problem
  - Start with null policy
  - Start with random policy

Not focus of this talk!



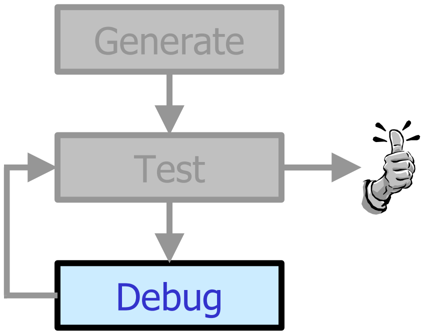
Test

- Use discrete event simulation to generate sample execution paths
- Use acceptance sampling to verify probabilistic CSL goal conditions

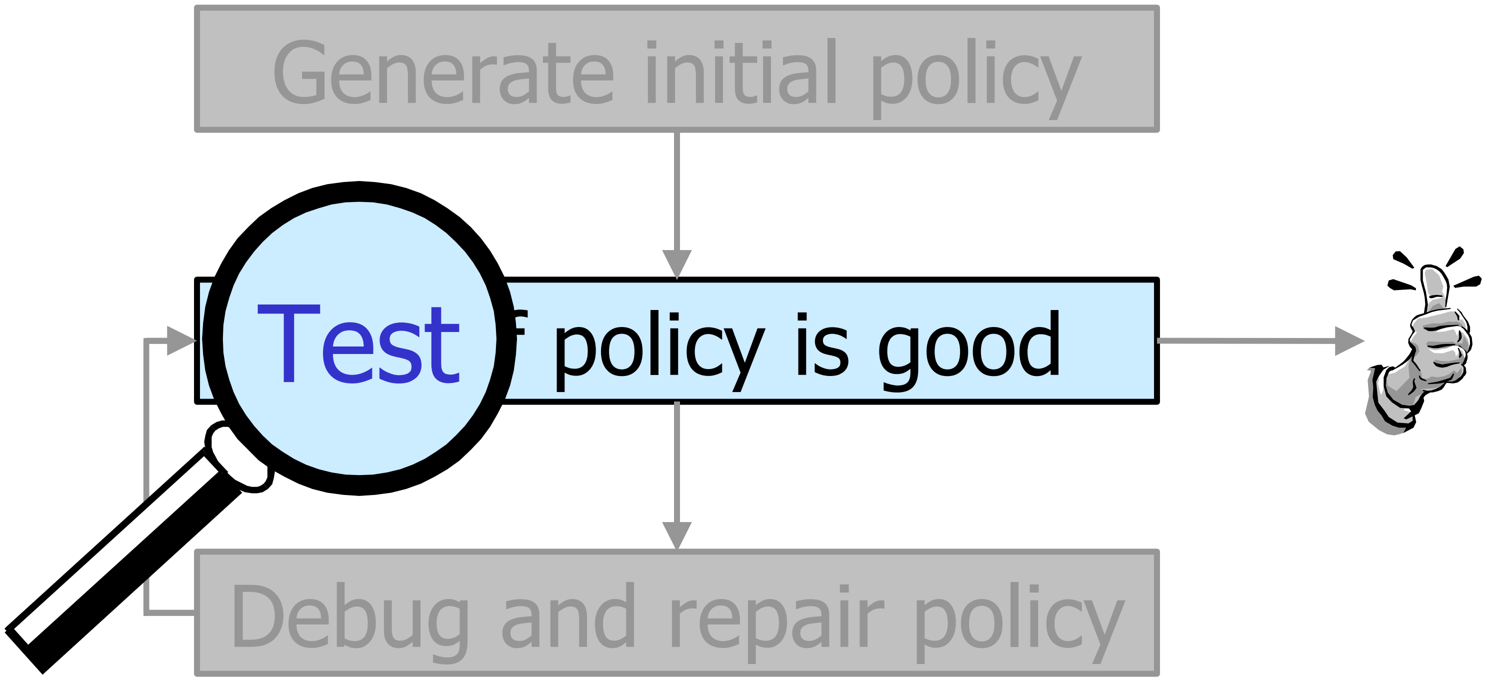


Debug

- Analyze sample paths generated in test step to find reasons for failure
- Change policy to reflect outcome of failure analysis



More on Test Step



Error Due to Sampling

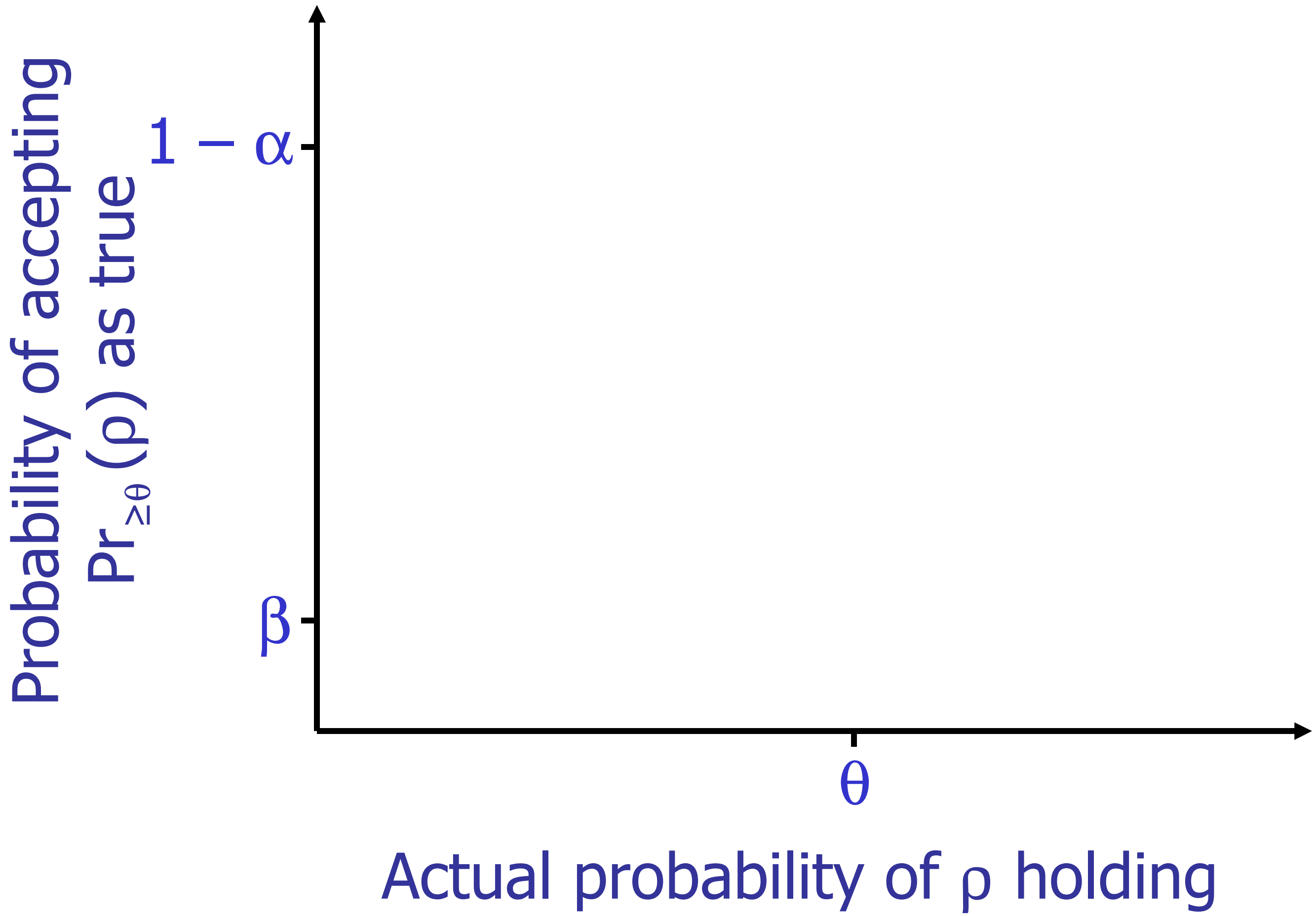
- Probability of false negative: $\leq\alpha$
  - Rejecting a good policy
- Probability of false positive: $\leq\beta$
  - Accepting a bad policy

$\boxed{(1-\beta)\text{-soundness}}$

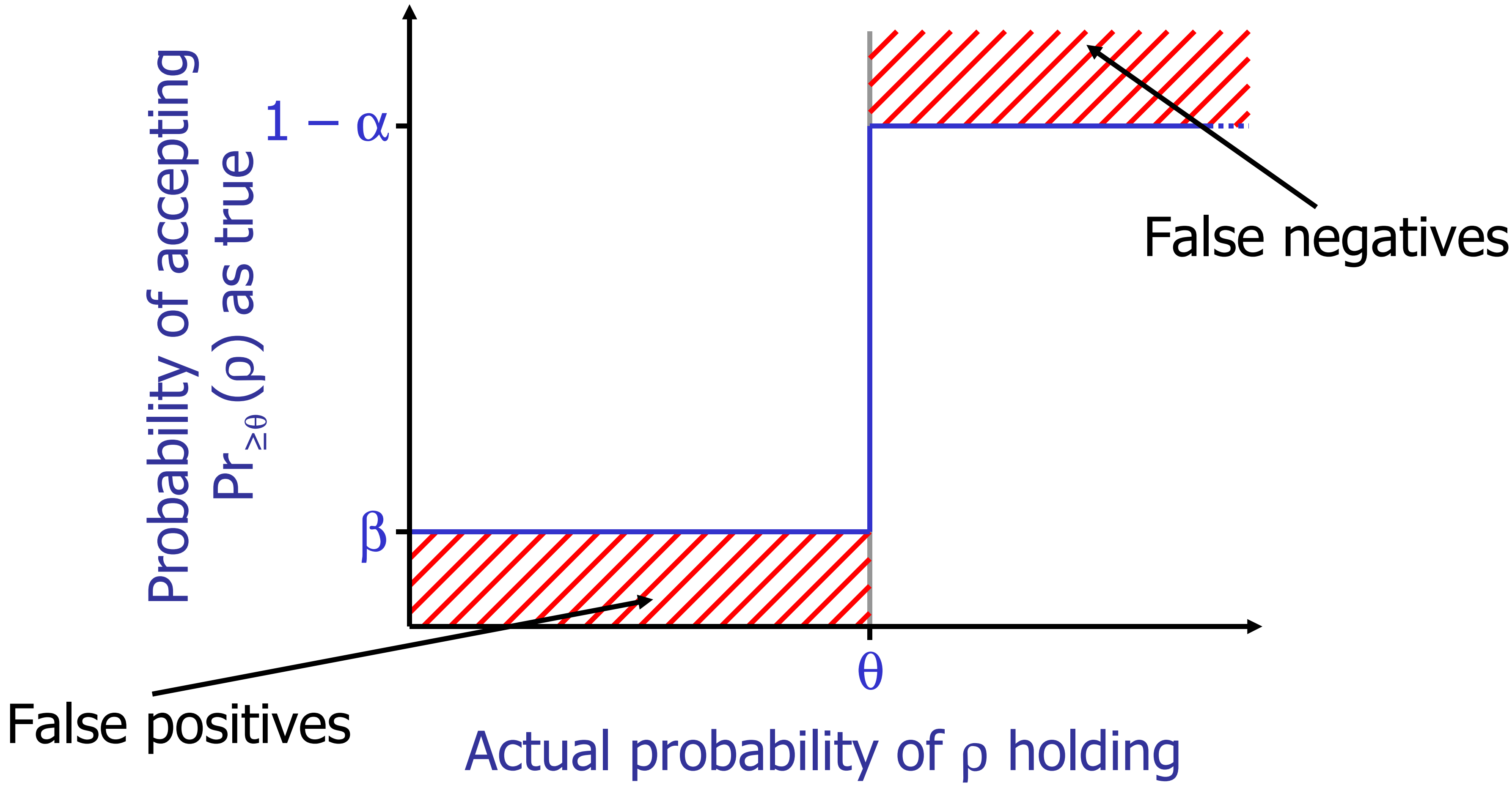
Acceptance Sampling

- Hypothesis: $Pr_{\geq\theta}(\rho)$

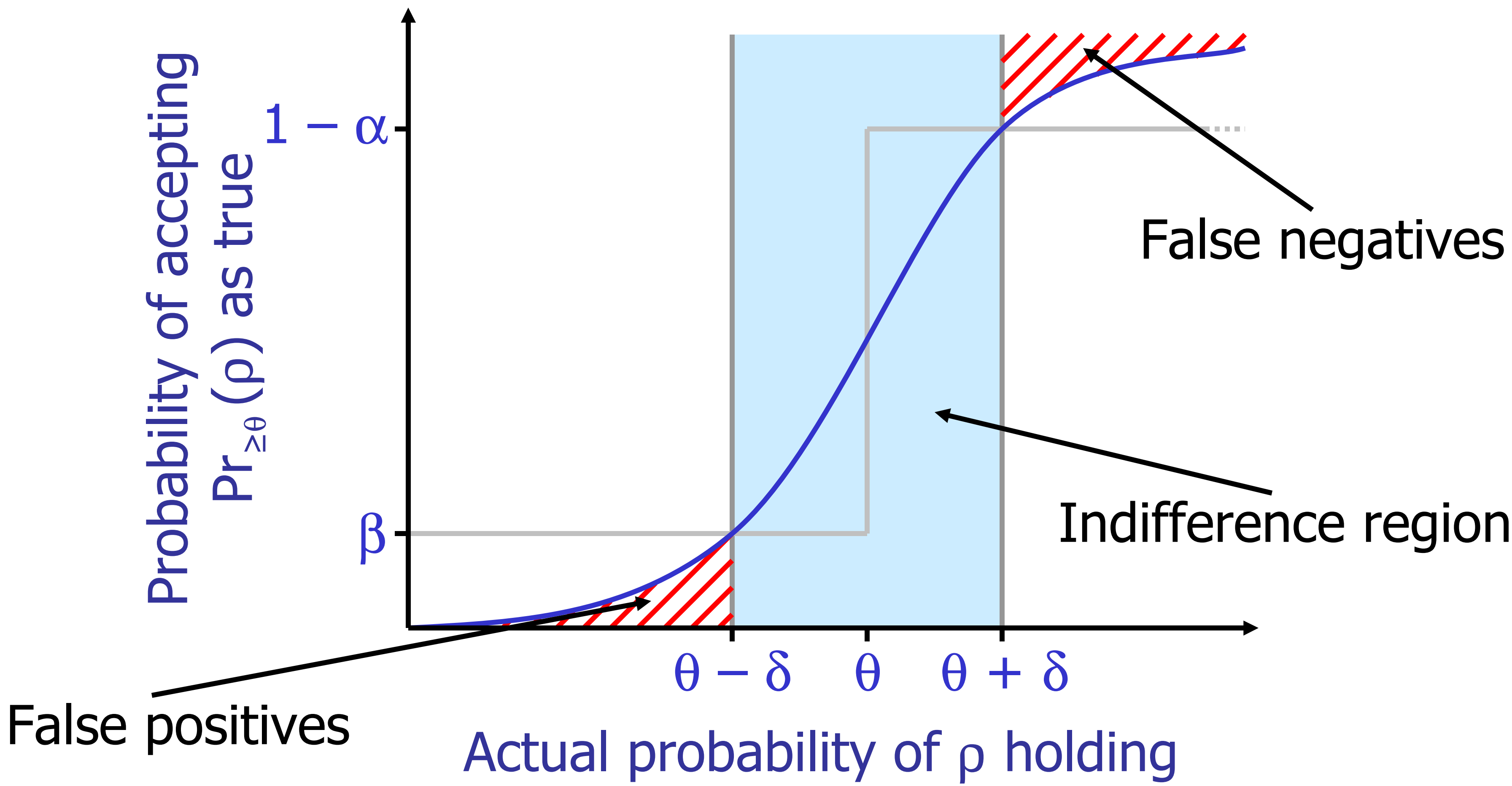
Performance of Test



Ideal Performance

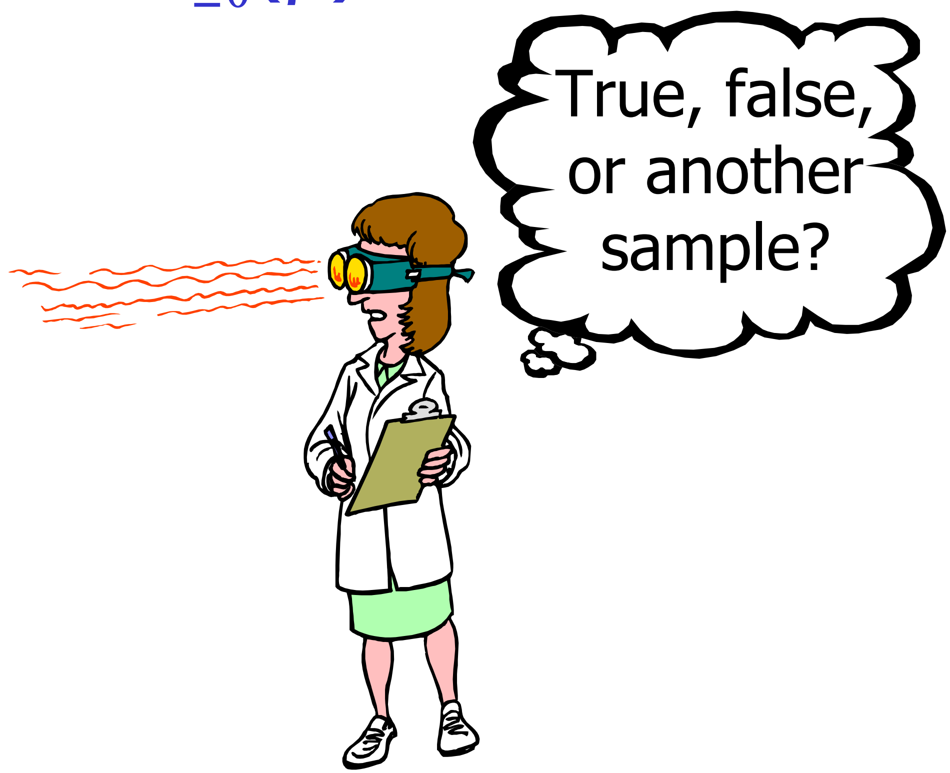


Realistic Performance

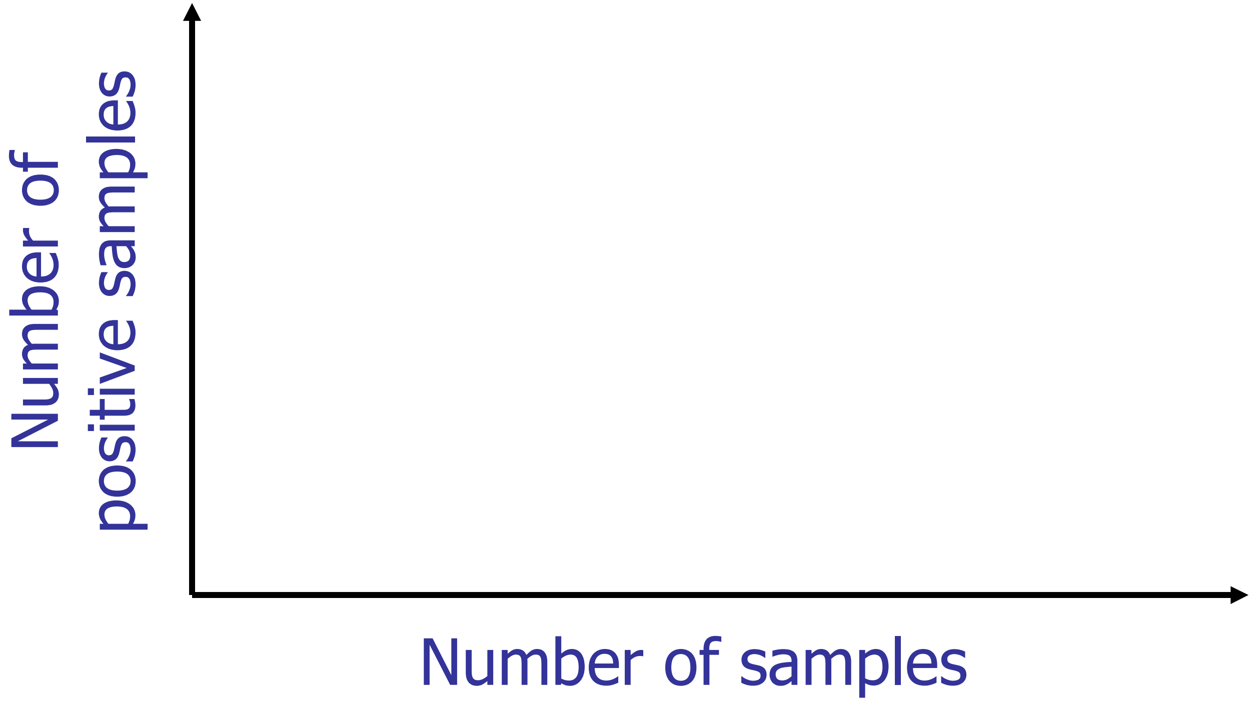


Sequential Acceptance Sampling [Wald 45]

- Hypothesis: $Pr_{\geq\theta}(\rho)$

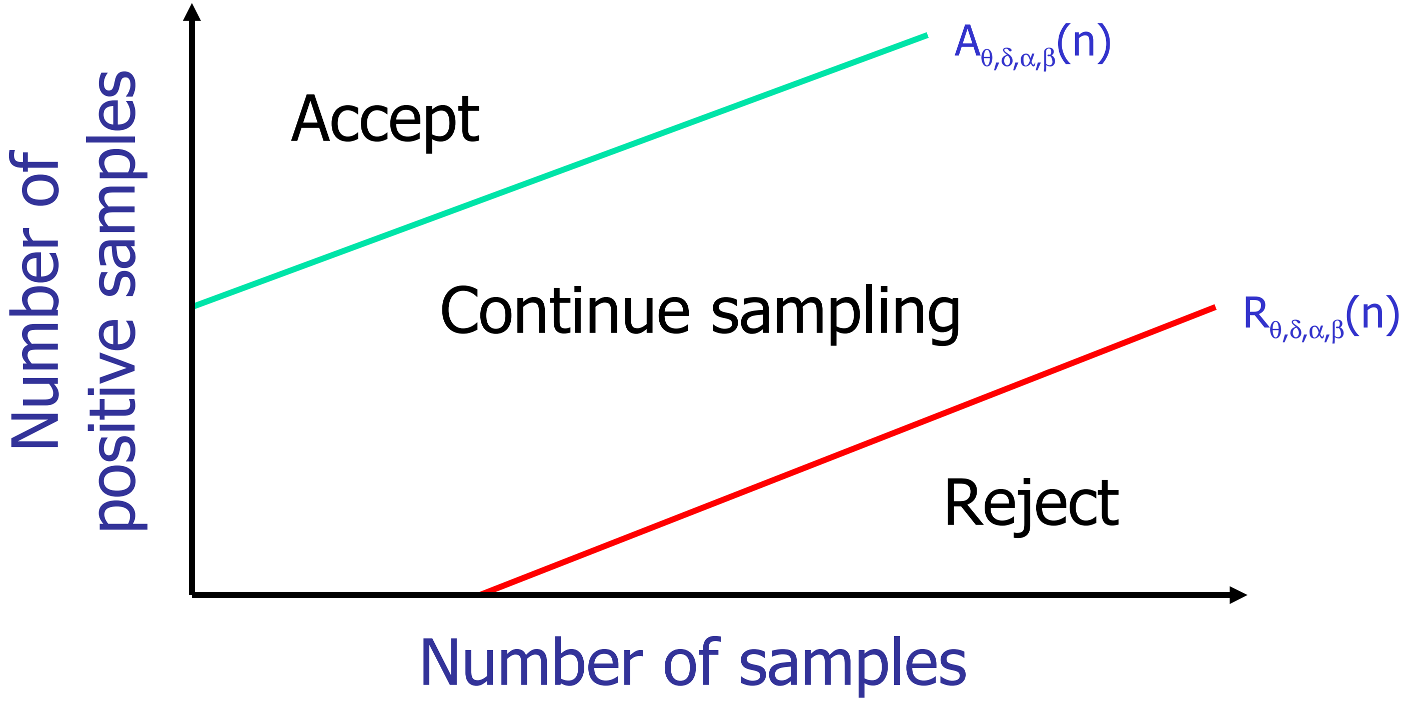


Graphical Representation of Sequential Test



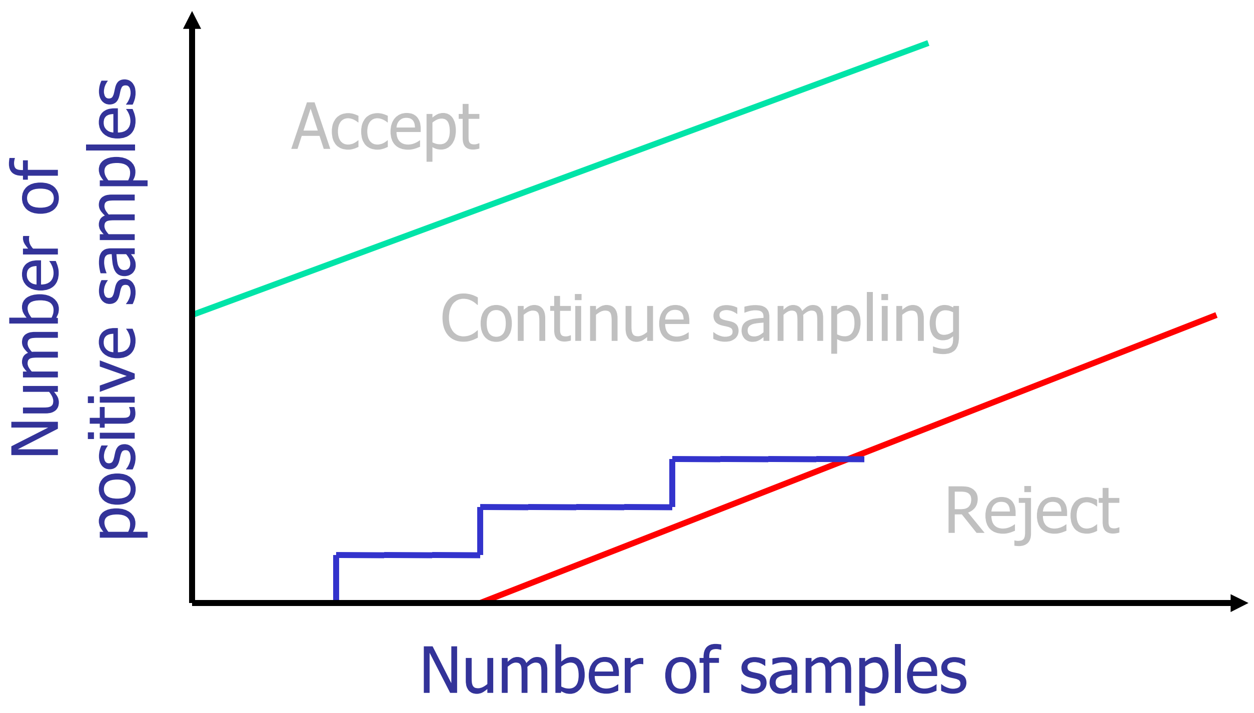
Graphical Representation of Sequential Test

- We can find an acceptance line and a rejection line given θ, δ, α, and β



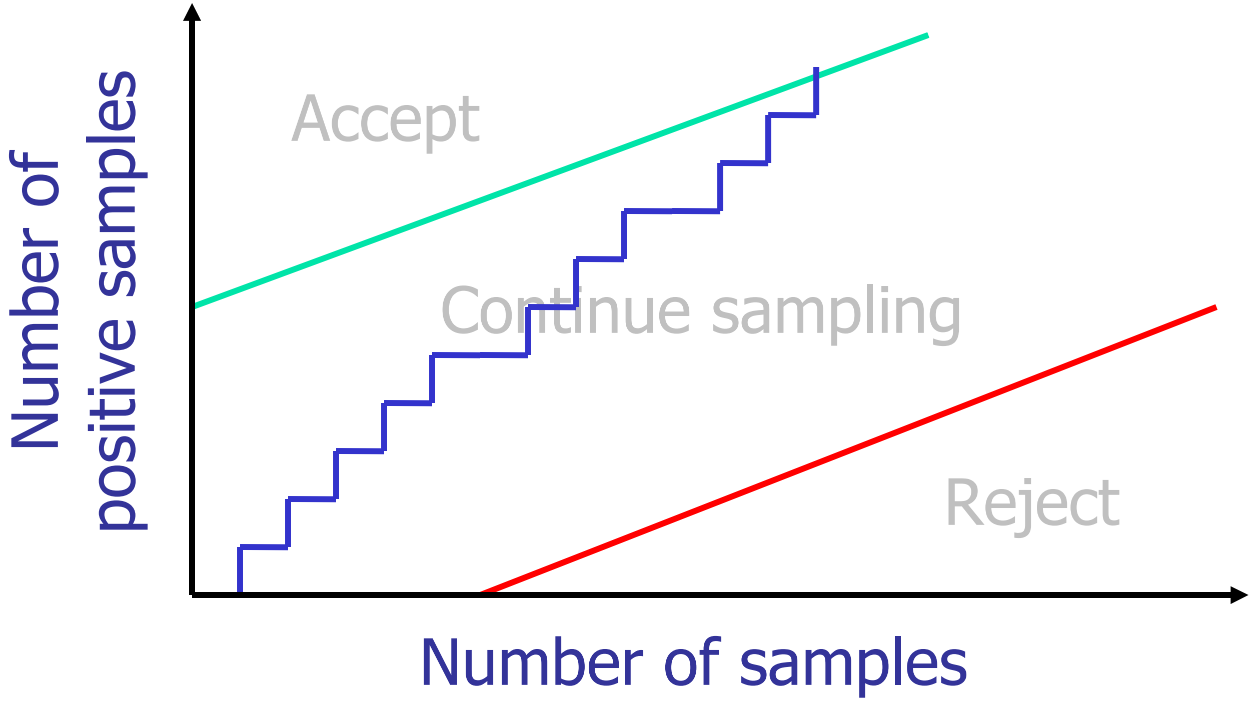
Graphical Representation of Sequential Test

- Reject hypothesis



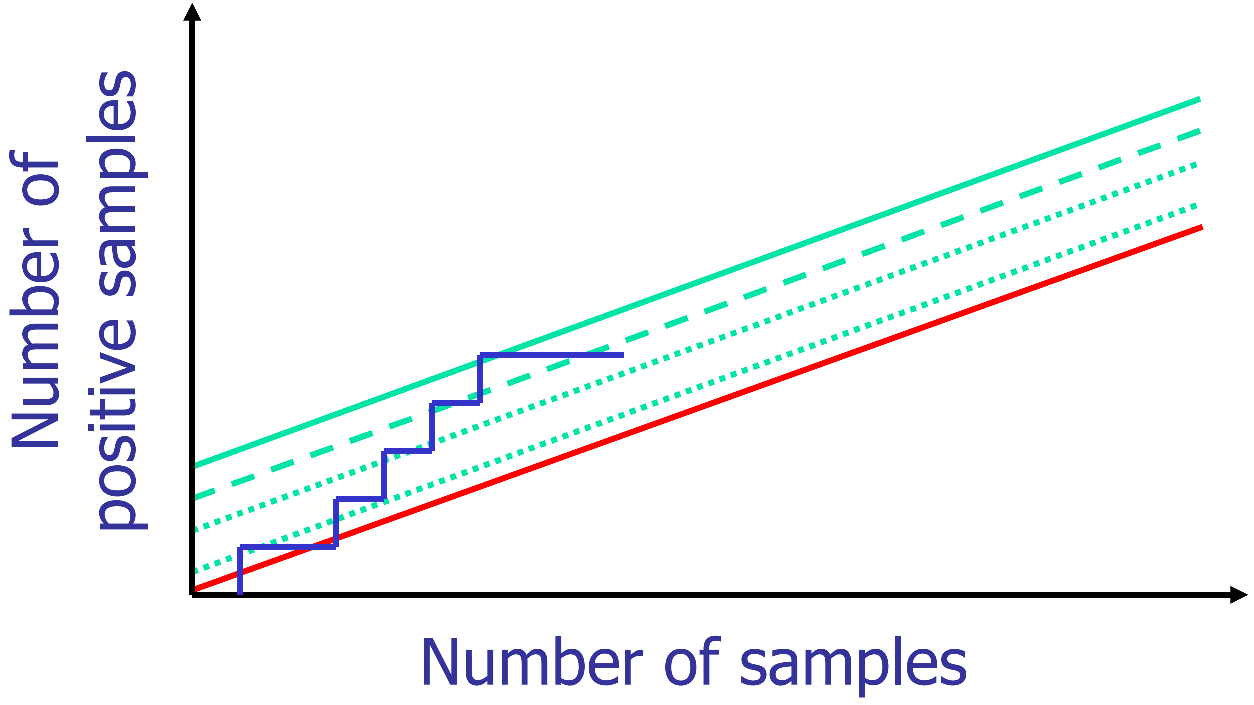
Graphical Representation of Sequential Test

- Accept hypothesis



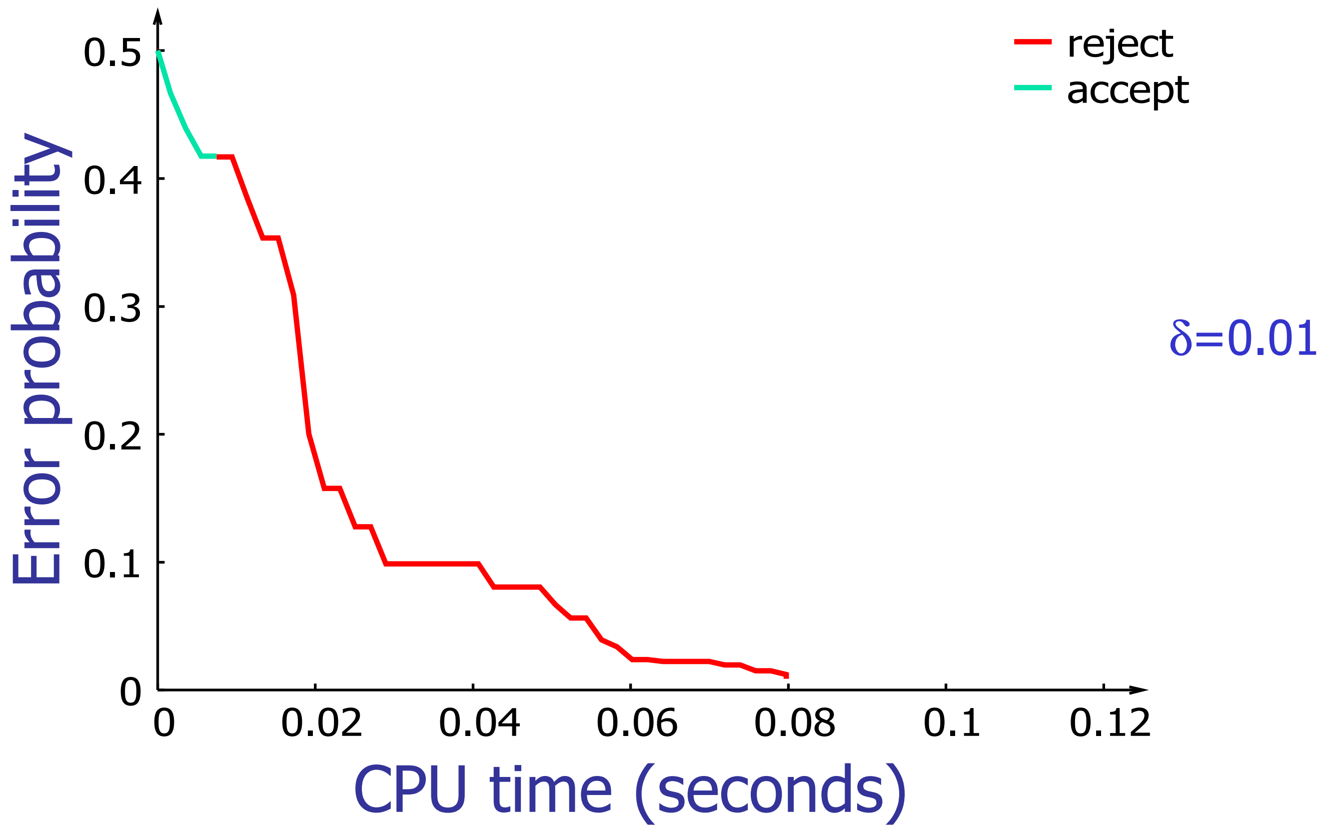
Anytime Policy Verification

- Find best acceptance and rejection lines after each sample in terms of α and β

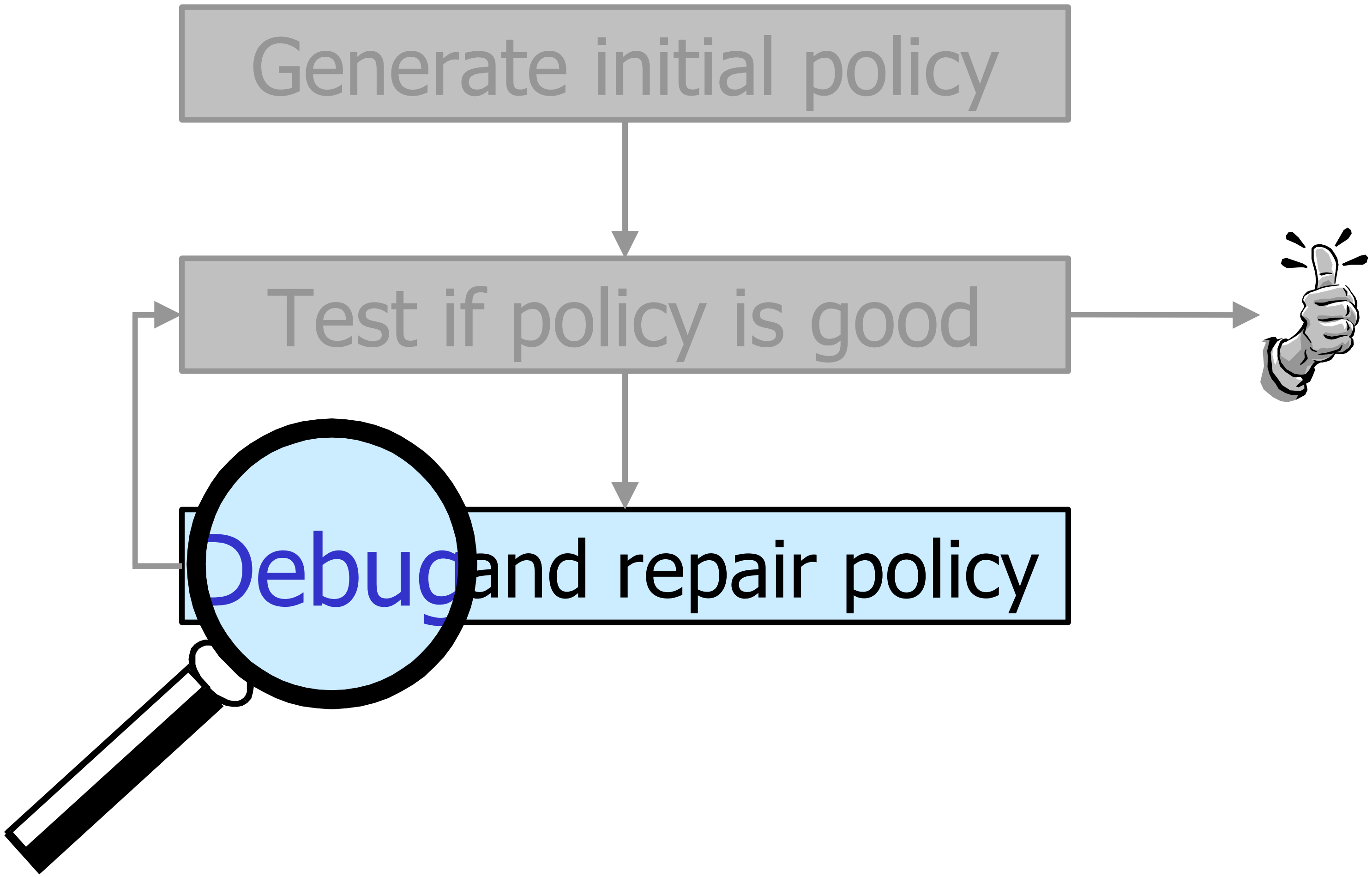


Verification Example

- Initial policy for example problem



More on Debug Step



Role of Negative Sample Paths

- Negative sample paths provide evidence on how policy can fail
  - “Counter examples”

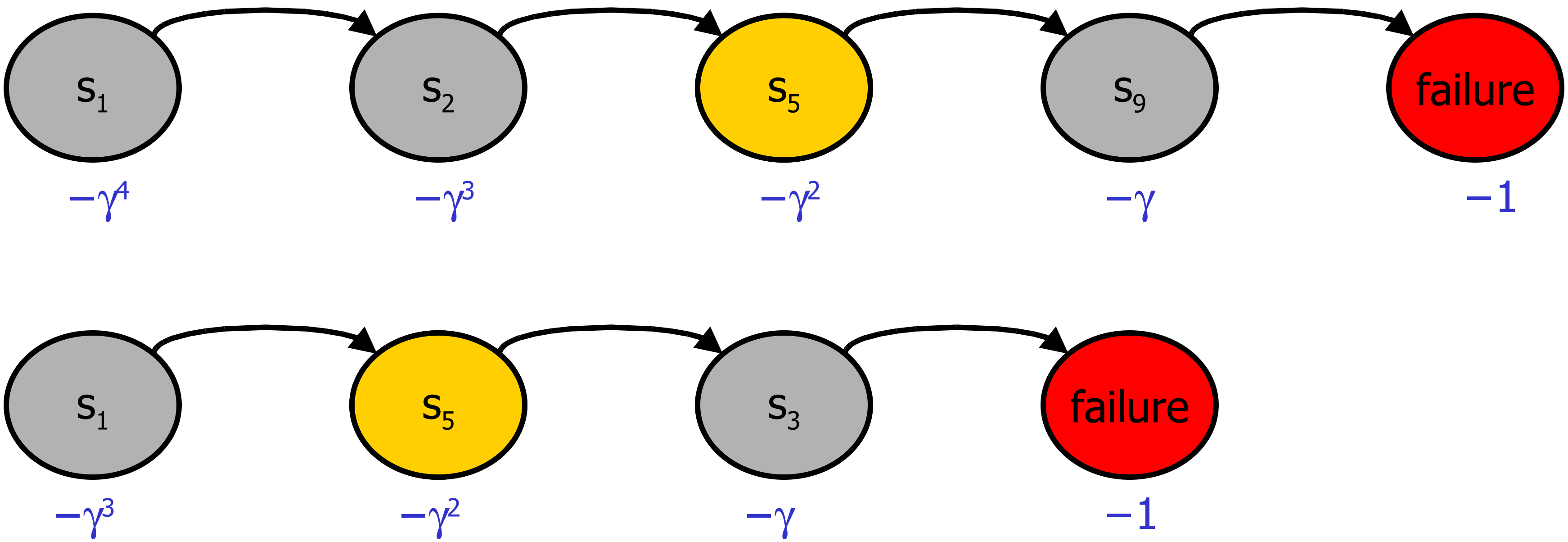
Generic Repair Procedure

1. Select some state along some negative sample path
2. Change the action planned for the selected state

Need heuristics to make informed state/action choices

Scoring States

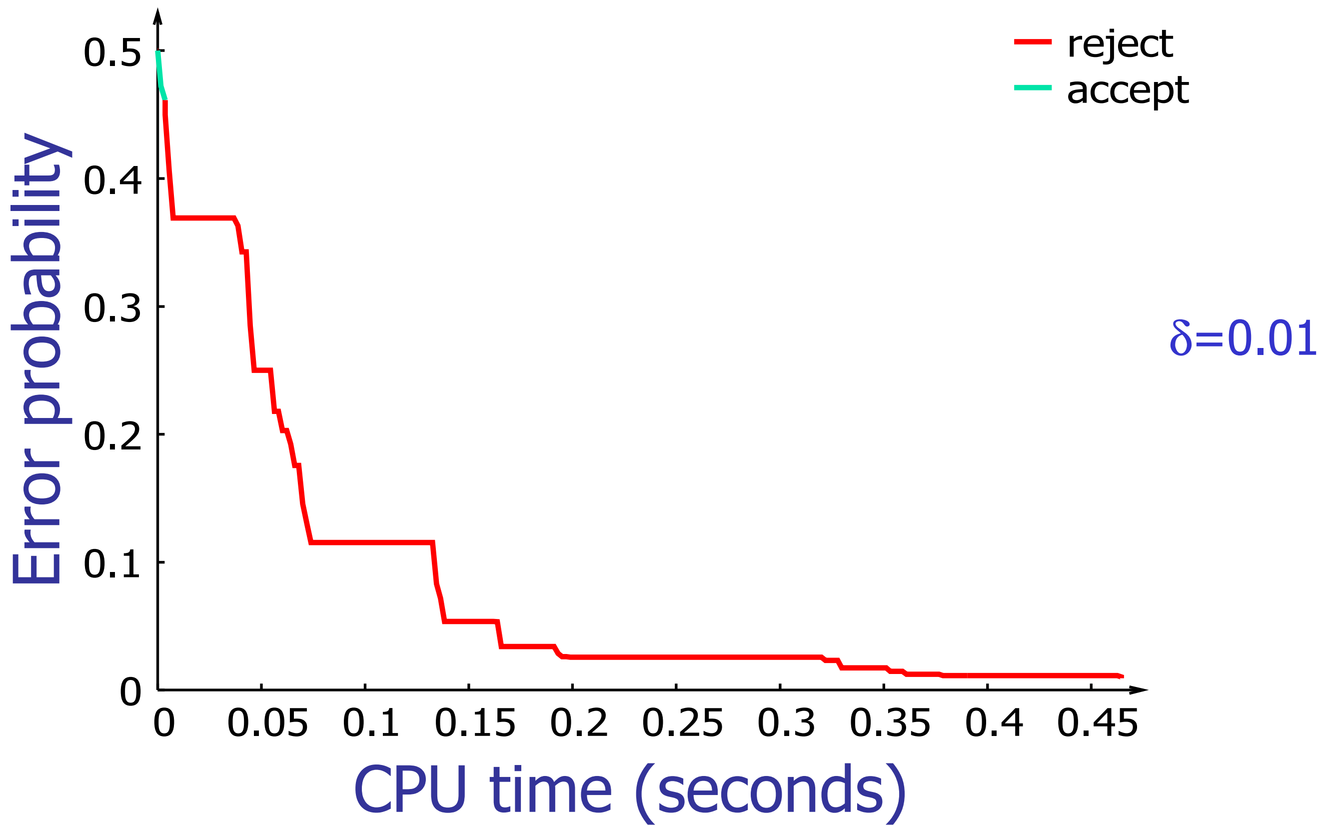
- Assign -1 to last state along negative sample path and propagate backwards
- Add over all negative sample paths



Example

- Package gets lost at Minneapolis airport while waiting for the taxi
- Repair: store package until taxi arrives

Verification of Repaired Policy



Comparing Policies

- Use acceptance sampling:
  - Pair samples from the verification of two policies
  - Count pairs where policies differ
  - Prefer first policy if probability is at least 0.5 of pairs where first policy is better

Summary

- Framework for dealing with complex stochastic domains
- Efficient sampling-based anytime verification of policies
- Initial work on debug and repair heuristics