11TH INTERNATIONAL COMMAND AND CONTROL RESEARCH TECHNOLOGY SYMPOSIUM (11TH ICCRTS) COALITION COMMAND AND CONTROL IN THE NETWORKED ERA

Applying Models Of Decision Making Under Uncertainty To Simulations Of Military Command And Control Systems

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Decision Making Modeling

Is and "Is Not's"

- This project is not attempting to model human cognition and decision making.
- This is a model of optimal decision making theory.
- Model provides a solution to the optimal action path for a problem based on minimum cost. In other words, it is a model designed to optimize the reward gained by making optimal decisions based on a reward structure.
- Approach:
  - Bayesian Statistics.
  - Partially Observable Markov Decision Processes.

Modeling Optimal Decision Making

Background

- Fundamental Aspect Of Human Cognition Is The Ability To Make Decisions.
- Most Decisions That Are Made Are Not "One Off" Decisions In Which The Decision Is Made And Then The Rewards Reaped Or The Punishment Endured.
- One Challenge Faced By Any Decision Maker Is The Uncertainty That The Decision Maker Has About The **True** State Of The System.
  - Generally The True State Of The System Is Unknown Or Hidden.
  - True State Cannot Be Directly Observed.
- Typical Response Can Be Characterized By The Observe-Orient-Decide-Act (OODA) Cycle.*
  - Observe: Example Is To Send A UAV To Find The Enemy.
  - Orient: Example Is To Update Belief About The Enemy Based On UAV Report.
  - Decide: Example Is To Declare Mission Complete And Take Appropriate Followon Actions
  - Act: Example Is To Take Action To Kill Enemy Such As Firing Artillery At Suspected Location.

* Belknap, M. (1996). Military Decision Making in the Information Age. Unpublished Monograph, Naval War College, Newport, RI. Joint Military Operations Department. Ad-a307-648-6-xab.

Modeling Optimal Decision Making

Approach

- Optimal Observer.
  - To evaluate performance in a task that leads to uncertainty and probabilistic actions, it is useful to determine the optimal performance within a task.
  - The optimal performance can be calculated using an extension of Bayesian statistics called *Partially Observable Markov Decision Processes* (POMDP).
  - Optimal performance can then be used as a benchmark by which to compare human performance.

- Belief Updating.
  - Hypotheses can be generated about the current state of the problem following an action and the returned observation.

Bayesian Updating Rule

$$p(s'|b,o,a) = \frac{p(o|s',b,a)\, p(s'|b,a)}{p(o|b,a)}$$

s' = true state (of the condition being present within the total of all states, S)
b = prior belief
o = observation
a = action that was generated

Updating the Belief Vector

With Enemy residing at State1 & initial Belief Vector = [0.5, 0.5, 0.0]

Belief Vector after first action of Recon to State1 =

p(State1 | [0.5, 0.5, 0.0], "EnemySighted",Recon1) = 0.7895
p(State2 | [0.5, 0.5, 0.0], "EnemySighted",Recon1) = 0.2105
p(StateDead | [0.5, 0.5, 0.0], "EnemySighted",Recon1) = 0.0000

Or

[0.7895, 0.2105, 0.0000]

Meaning

78.95%	probability of belief that the enemy is still in State1.
21.05%	probability of belief that the enemy is in State2.
0.0000%	probability of belief that the enemy is in State Dead (i.e., belief that the enemy is not still alive).

Control Parameters for Determining the Action Sequence

Δ $\equiv$ (Delta) Declare Threshold; if the Belief Probability of Enemy Destroyed $\geq \Delta$, then Declare. Δ only refers to the DEAD state.

σ $\equiv$ (Sigma) Shoot Threshold; if the Belief Probability of Enemy Destroyed $\geq \sigma$, then Shoot, otherwise Look. σ only refers to the LOCATION states.

Conditional Probability Expression

The probability of the next action being to S1 is given by:

$P(S1 \mid !S3) = CP1 = (P(S1) / (P(S1) + P(S2))$

Likewise for S2:

$P(S2 \mid !S3) = CP2 = (P(S2) / (P(S1) + P(S2))$

If $CP \geq \sigma$ then Look, otherwise Shoot.

If $S3 \geq \Delta$ then declare mission complete.

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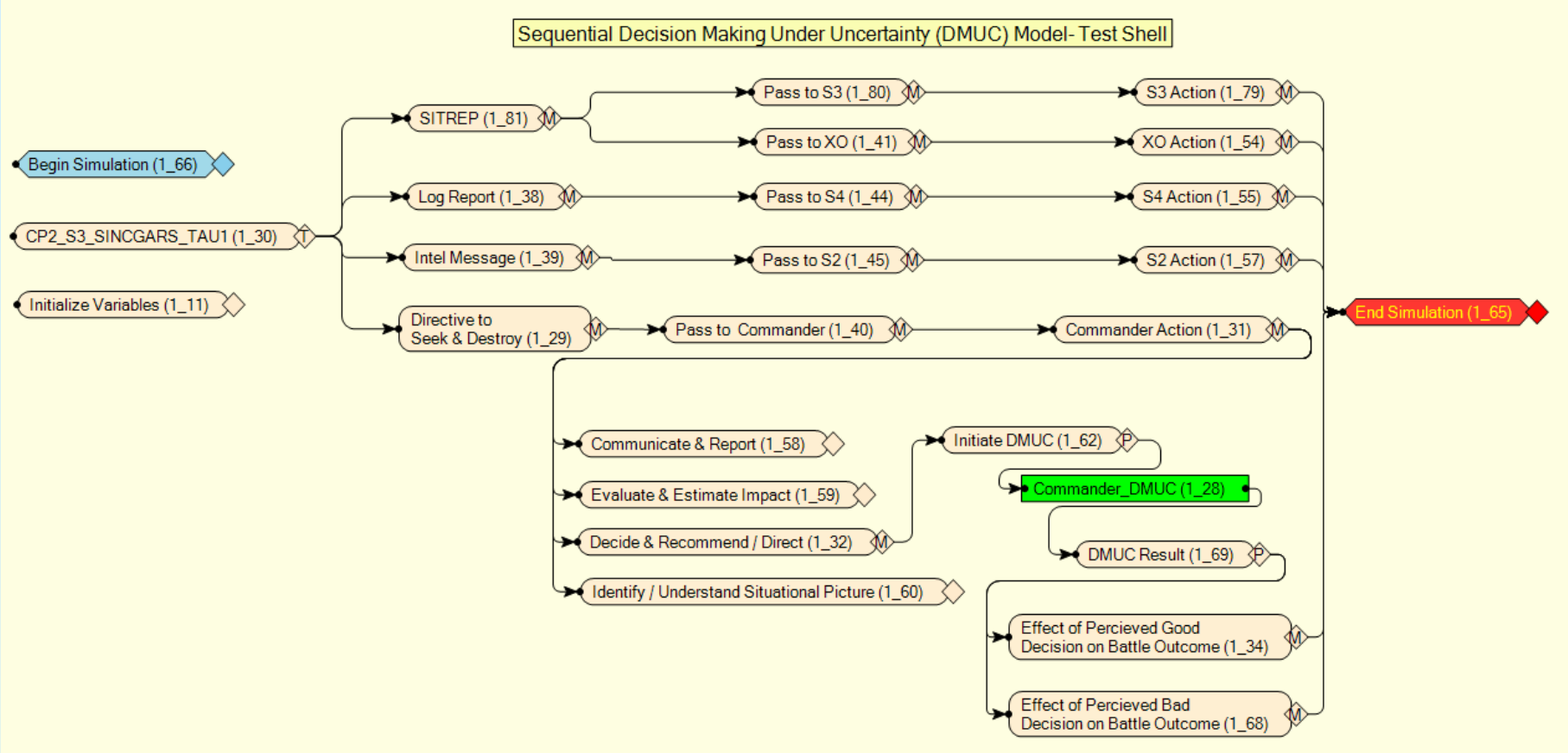
Example: Command and Control Simulation Vignette



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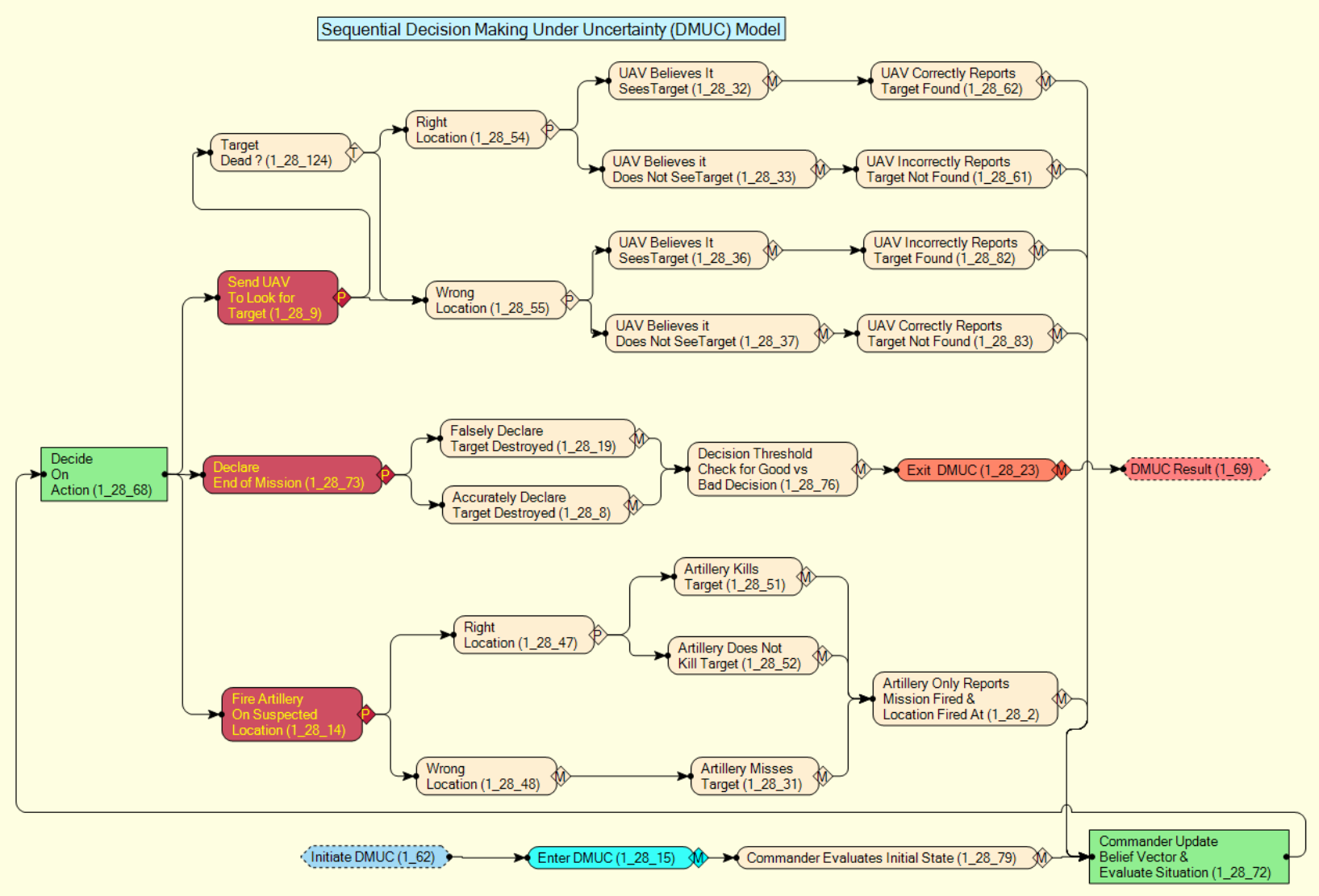
Decision Making Under Uncertainty Model



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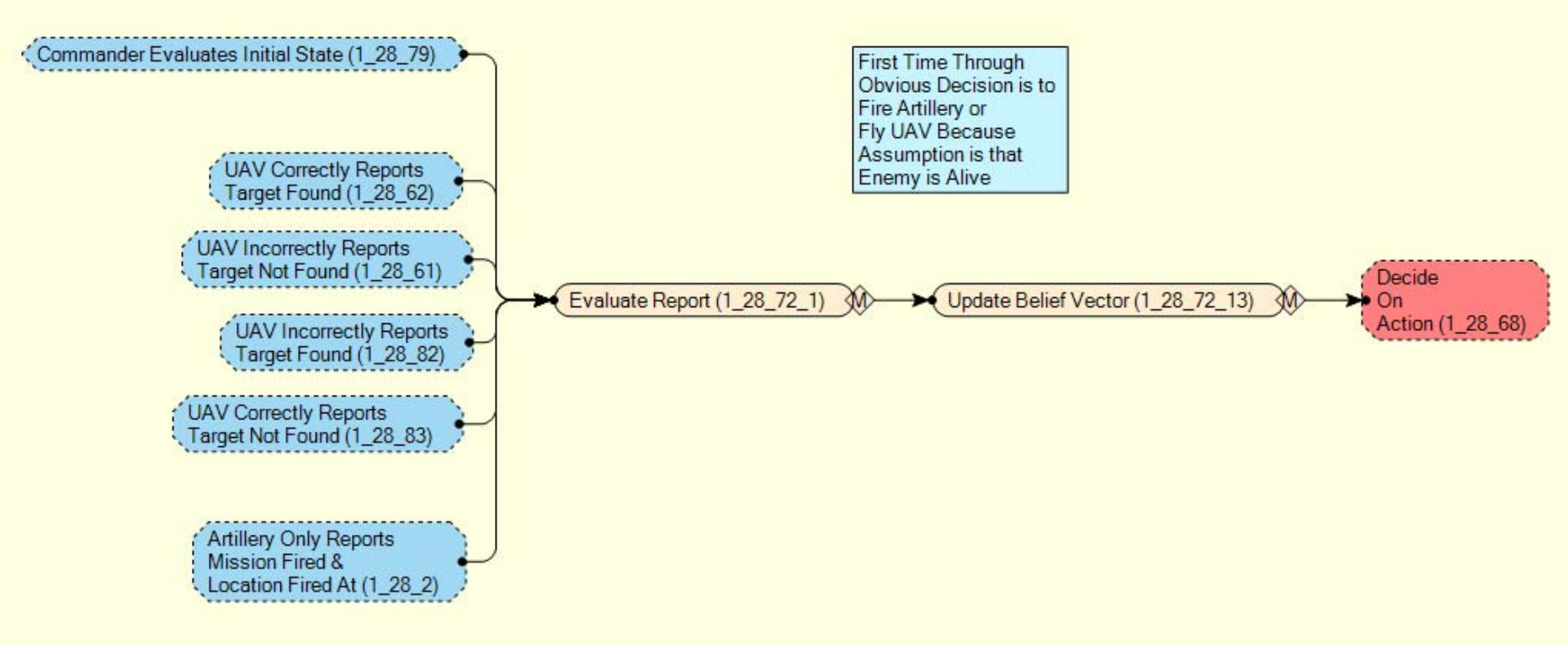
Modeling of Belief Updating



Belief Vector Updating Logic

If the action generated was to Look, then update the BV from the look mission:
- **Do** for each state:
- **Calculate** PoGs'ba from Table 1 lookup.
- **Calculate** Ps'Gba from previous belief probability of the enemy in the state occupied.
- **Calculate** PoGba from:
  - (Probability of Enemy in State Action To * Table 1 Lookup for that State) +
  - (Probability of Enemy in State Action Not To * Table 1 Lookup for that State) +
  - (Probability of Enemy in State Dead * Table 1 Lookup for condition applicable to State Dead)
- **Calculate** Ps'Gboa from: (PoGs'ba * Ps'Gba) / PoGba
- **Equate** the BV component for that state = Ps'Gboa.
- **End Do**

Else if the action generated was to Shoot, then update BV from the shoot mission:
- **Do** for each state:
- **Calculate** PoGs'ba from Table 2 lookup which will always = 1.0.
- **Calculate** Ps'Gba from:
  - [Probability (In-State) x (previous probability for State Struck] +
  - [(1.0- Probability (Out-State) x (previous probability for State Occupied)]
- **Calculate** PoGba from Table 2 lookup which will always = 1.0.
- **Calculate** Ps'Gboa from: (PoGs'ba * Ps'Gba) / PoGba
- **Equate** the BV component for that state = Ps'Gboa.
- **End Do**

End

Conditional Probability Updating Logic

Do

Calculate CP1 = PS1 / (PS1 + PS2)
Calculate CP2 = PS2 / (PS1 + PS2)

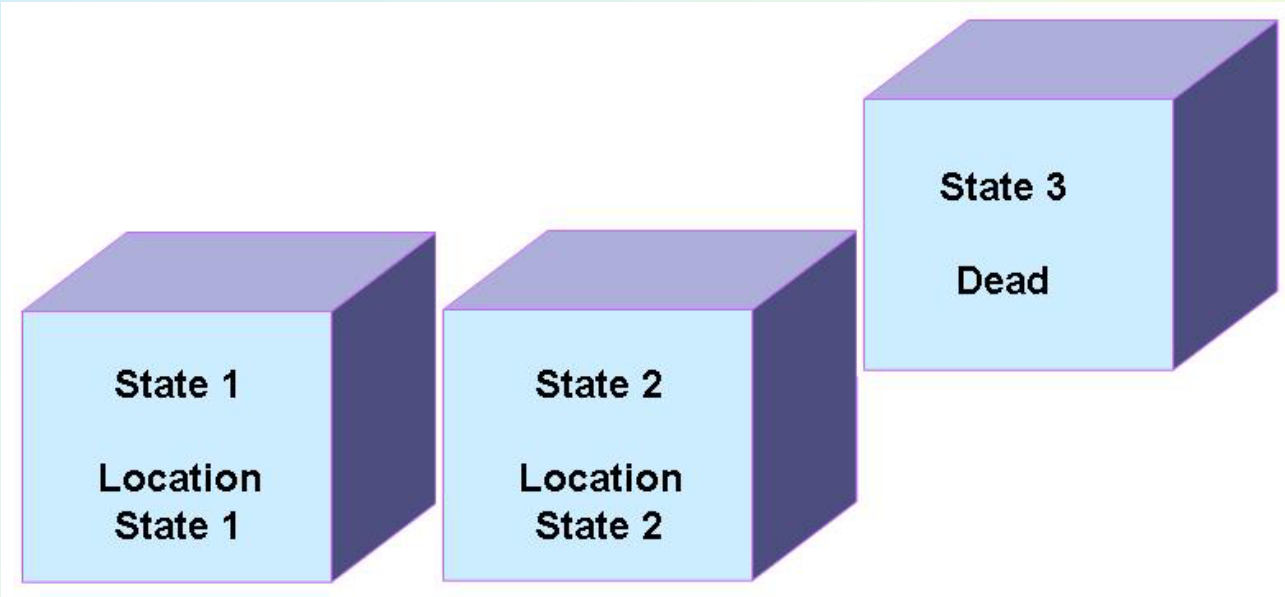
End Do

If ((CP1 & CP2) < σ) then
If (CP1 > CP2) then LOOK at S1
If (CP1 < CP2) then LOOK at S2
If (CP1 = CP2) then LOOK at Random pick of S1 or S2
End If
If (CP1 > σ) then SHOOT at S1
If (CP2 > σ) then SHOOT at S2
If ((CP1 > σ) & (CP2 > σ)) then SHOOT at Random pick of S1 or S2

Calculate new BV
If ((BV component for S3) > Δ) then
Declare mission complete
Else continue processing and go to next iteration

Modeling Optimal Decision Making

State Space Matrix for Initial Model Development



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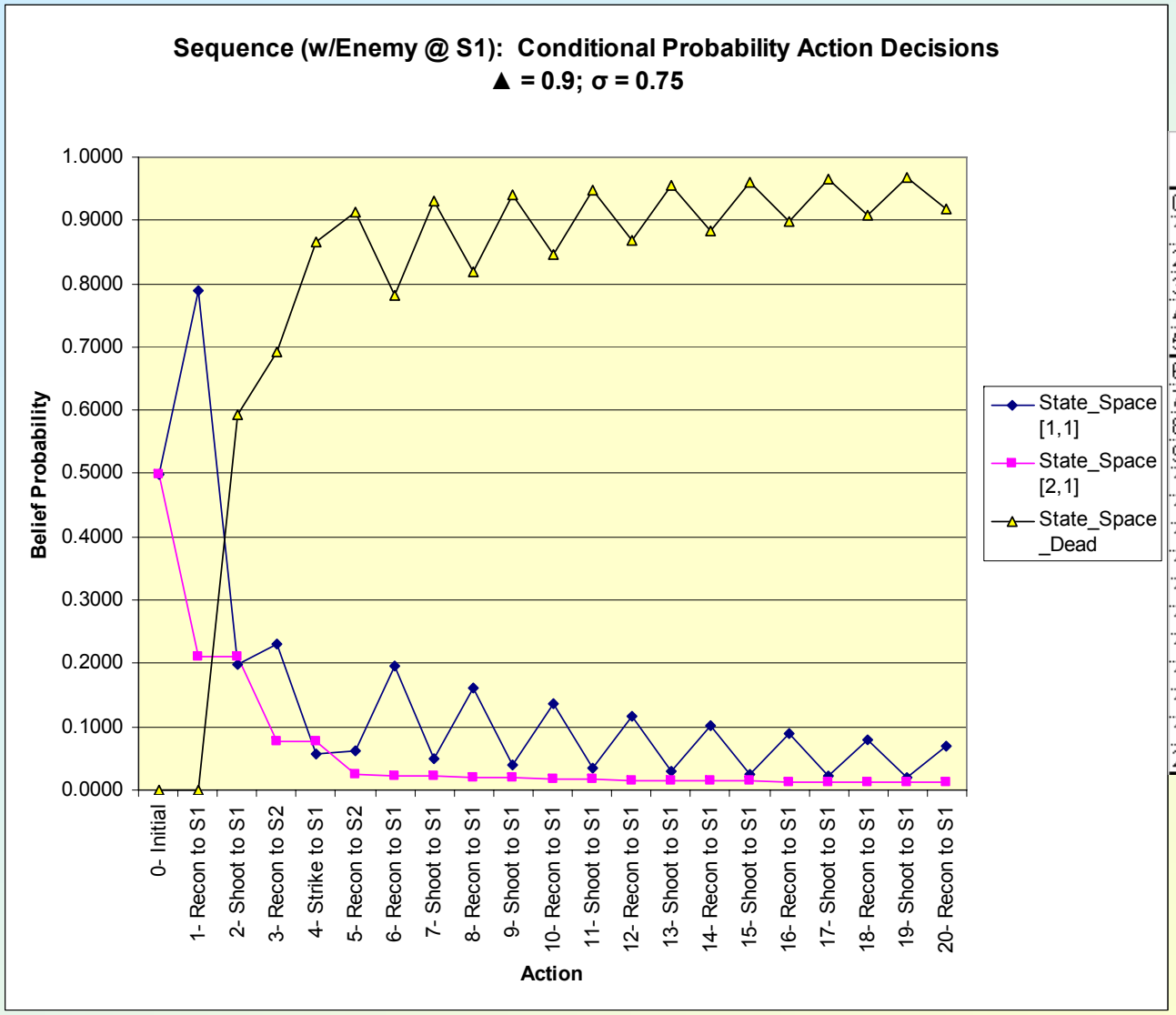

Action	State_Space [1,1]	State_Space [2,1]	State_Space _Dead
0- Initial	0.5000	0.5000	0.0000
1- Recon to S1	0.7895	0.2105	0.0000
2- Shoot to S1	0.1974	0.2105	0.5921
3- Recon to S2	0.2308	0.0769	0.6923
4- Shoot to S1	0.0577	0.0769	0.8654
5- Recon to S2	0.0609	0.0254	0.9137
6- Recon to S1	0.1957	0.0217	0.7826
7- Shoot to S1	0.0489	0.0217	0.9293
8- Recon to S1	0.1617	0.0192	0.8192
9- Shoot to S1	0.0404	0.0192	0.9404
10- Recon to S1	0.1364	0.0172	0.8463
11- Shoot to S1	0.0341	0.0172	0.9487
12- Recon to S1	0.1169	0.0158	0.8673
13- Shoot to S1	0.0292	0.0158	0.9550
14- Recon to S1	0.1015	0.0146	0.8840
15- Shoot to S1	0.0254	0.0146	0.9600
16- Recon to S1	0.0889	0.0136	0.8974
17- Shoot to S1	0.0222	0.0136	0.9641
18- Recon to S1	0.0786	0.0129	0.9086
19- Shoot to S1	0.0196	0.0129	0.9675
20- Recon to S1	0.0699	0.0122	0.9179

Reward Structure Sequence by σ

Recon Cost	10			
Shoot Cost	100			
σ, Sigma- Sequence	RS		σ, Sigma- Sequence	RS
0.00- S1-S20	2000		0.74- RRSRS	230
0.01- SSSSSSS	700		0.75- RRSRS	230
0.05- SSSSSS	600		0.76- RRSRSRSRS	450
0.10- SSSSS	500		0.77- RRSRSRSRS	450
0.15- SSSSS	500		0.78- RRSRSRSRS	450
0.20- SSSSS	500		0.79- RSRRSRSRS	450
0.25- SSSS	400		0.80- RRSRSRSRS	450
0.30- SSSS	400		0.81- RRSRSRSRS	450
0.35- SSSS	400		0.82- RRSRSRSRS	450
0.40- SSSS	400		0.83- RRSRSRSRS	450
0.45- SSSS	400		0.84- RRSRSRSRS	450
0.50- SSSS	400		0.85- RRSRSRSRS	450
0.55- RSRSS	320		0.86- RRSRSRSRS	450
0.59- RSRSR	230		0.87- RRSRSRSRS	450
0.60- RSRSR	230		0.88- RRSRSRSRS	450
0.61- RSRSR	230		0.89- RRSRSRSRS	450
0.62- RSRSR	230		0.90- RRSRSRSRS	450
0.63- RSRSR	230		0.91- RRSRSRSRS	450
0.64- RSRSR	230		0.92- RRSRSRSRS	450
0.65- RSRSR	230		0.93- RRSRRSRSRS	460
0.66- RSRSR	230		0.94- RRRSRSRSRS	460
0.67- RSRSR	230		0.95- RRRSRSRSRS	460
0.68- RSRSR	230		0.96- RRRSRSRSRS	460
0.69- RSRSR	230		0.97- RRRSRSRSRS	460
0.70- RSRSR	230		0.98- RRRSRSRRSRSRS	580
0.71- RRSRS	230		0.99- RRRRSRSRS	360
0.72- RRSRS	230		1.00- 20R	200
0.73- RRSRS	230			

Reward Sequence by σ

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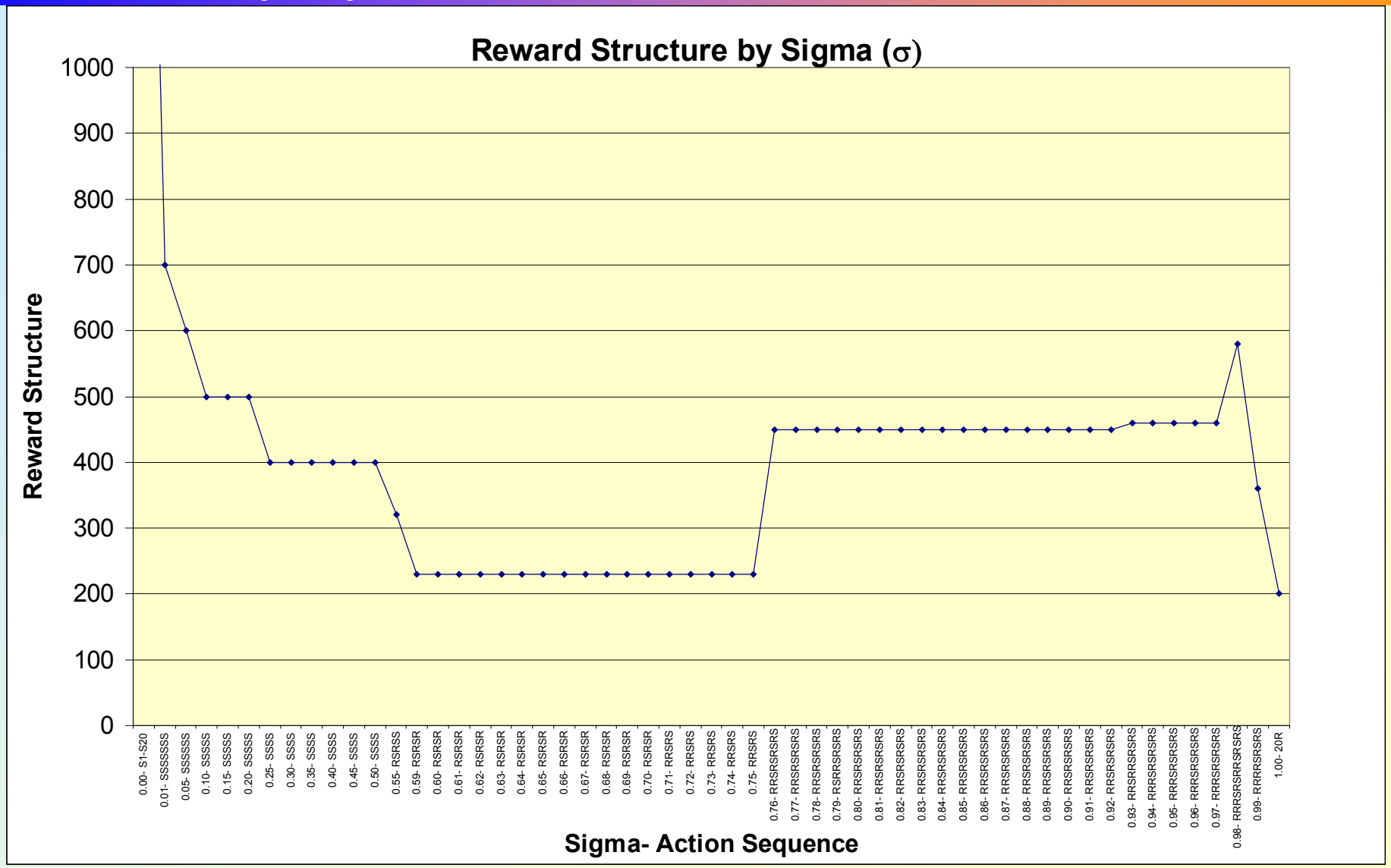
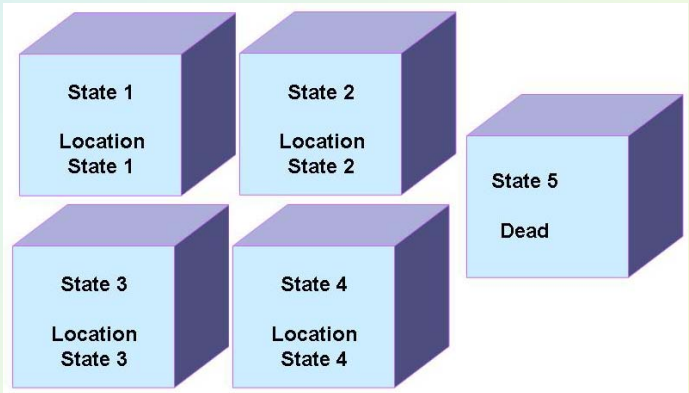


Modeling Optimal Decision Making

State Space Development

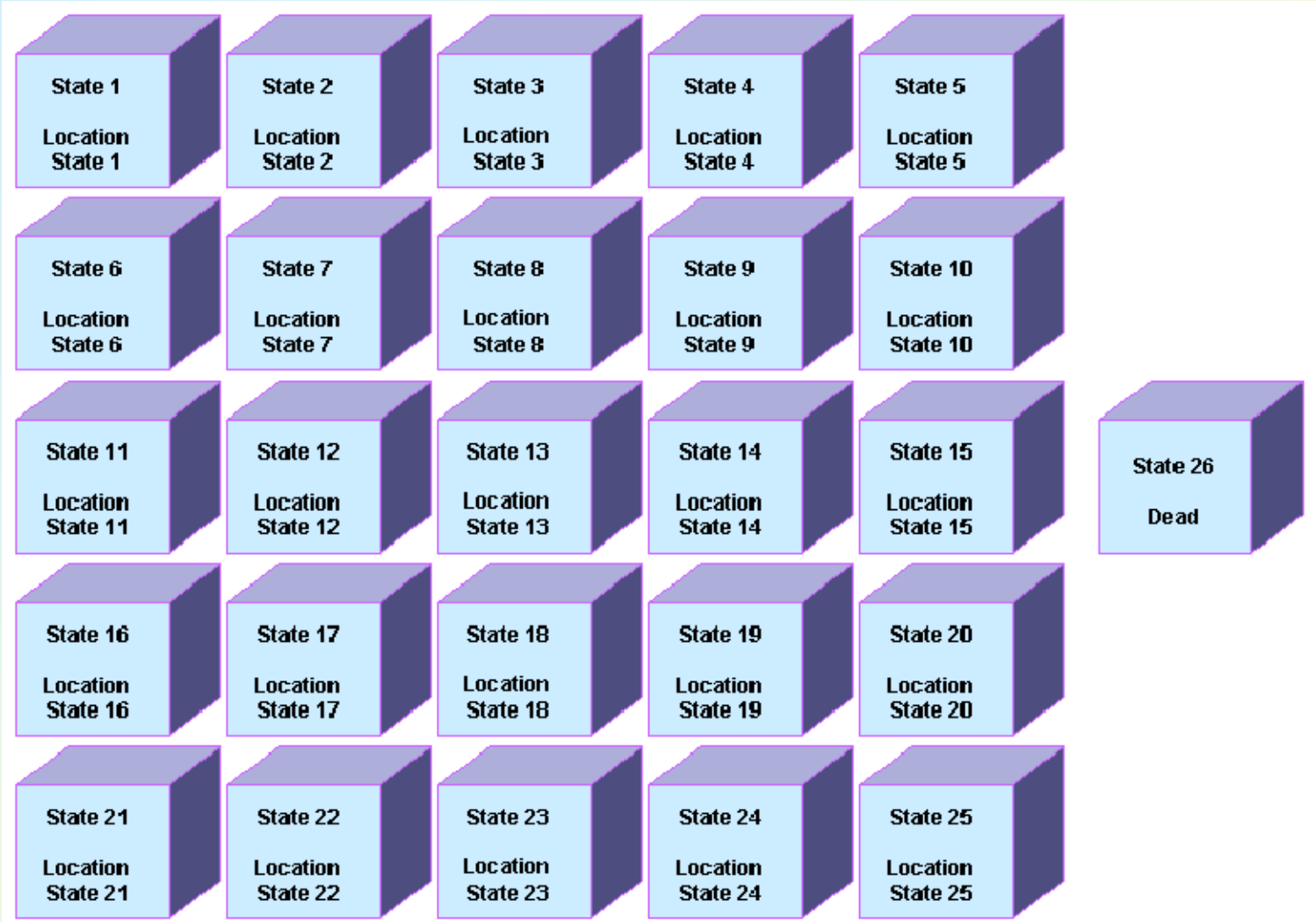
Next Step State Matrix



Modeling Optimal Decision Making

State Space Development

Target State Matrix



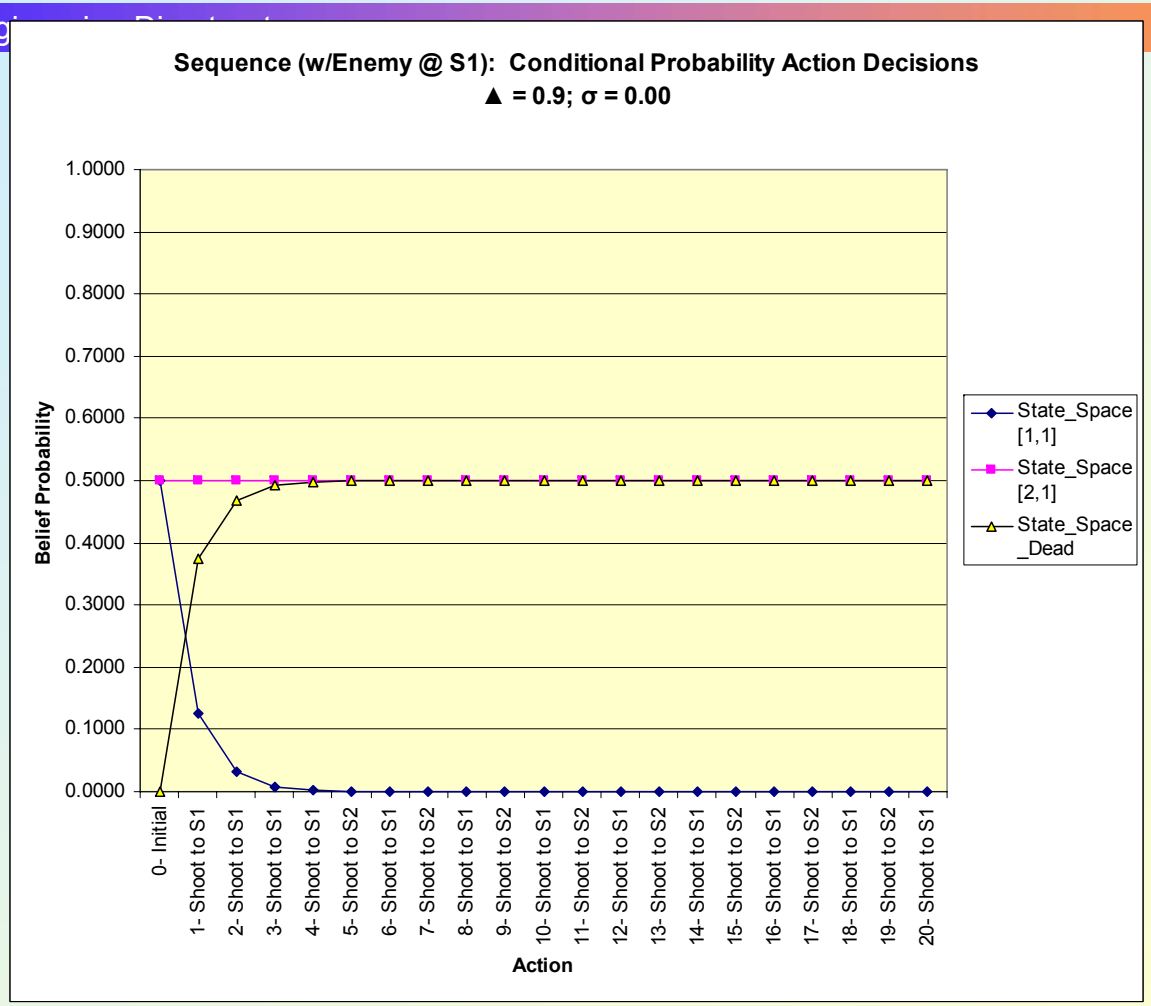
Questions?

Back Up Slides

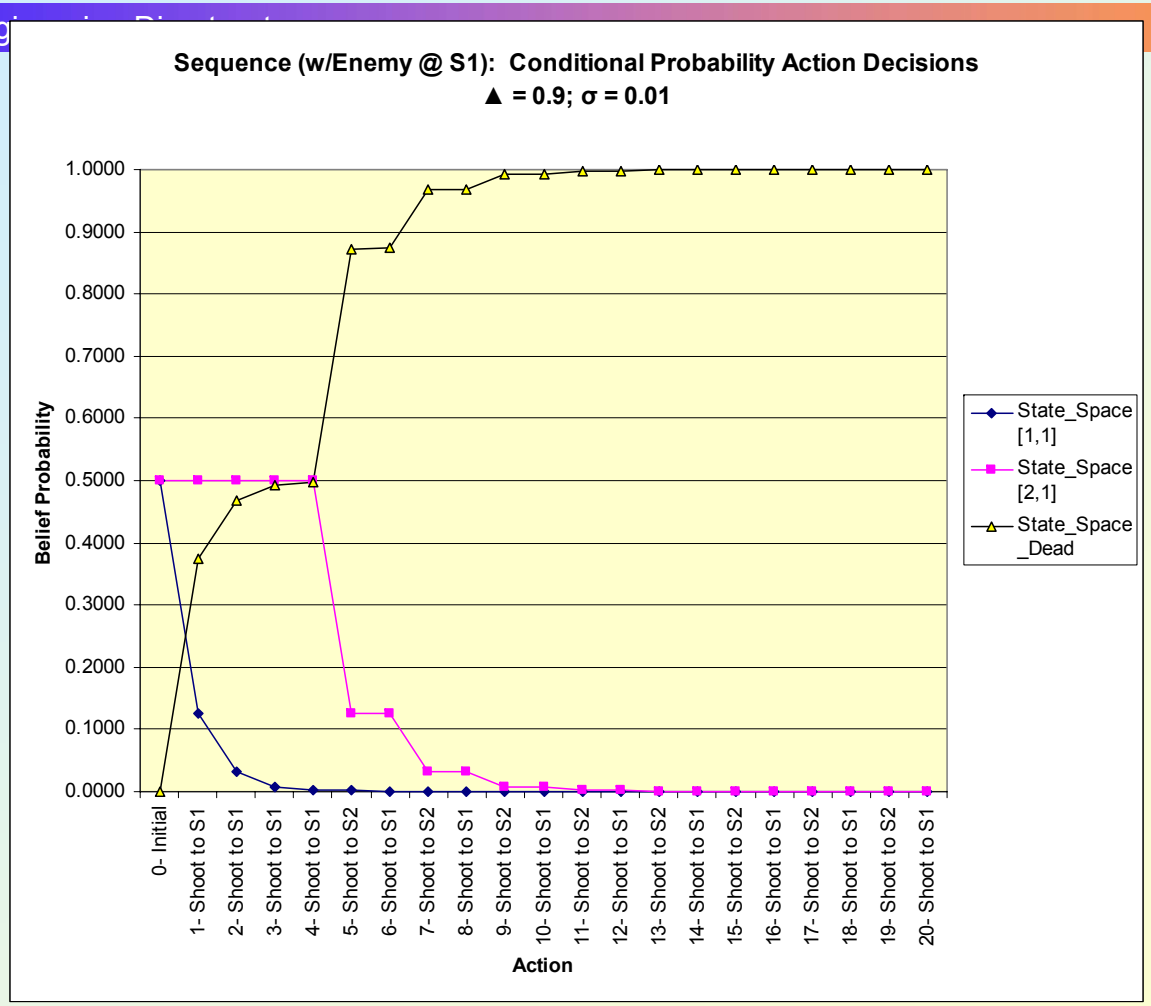
Belief Vector Sequence as σ Varies from 0.0 to 1.0 in 0.1 increments

(Gaps in increments indicate no change)

Action Decision Sequence by σ



Action Decision Sequence by σ



Action Decision Sequence by σ

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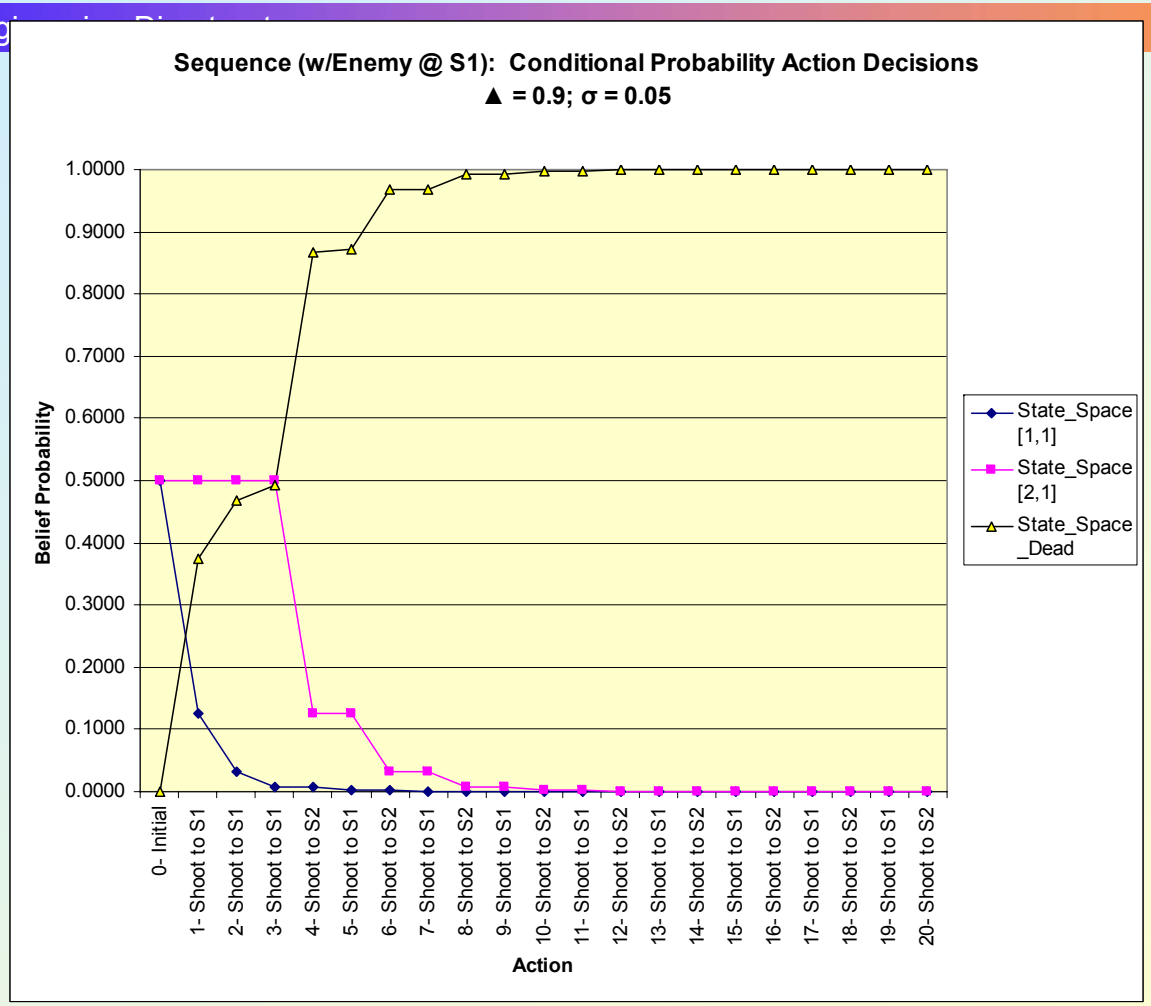

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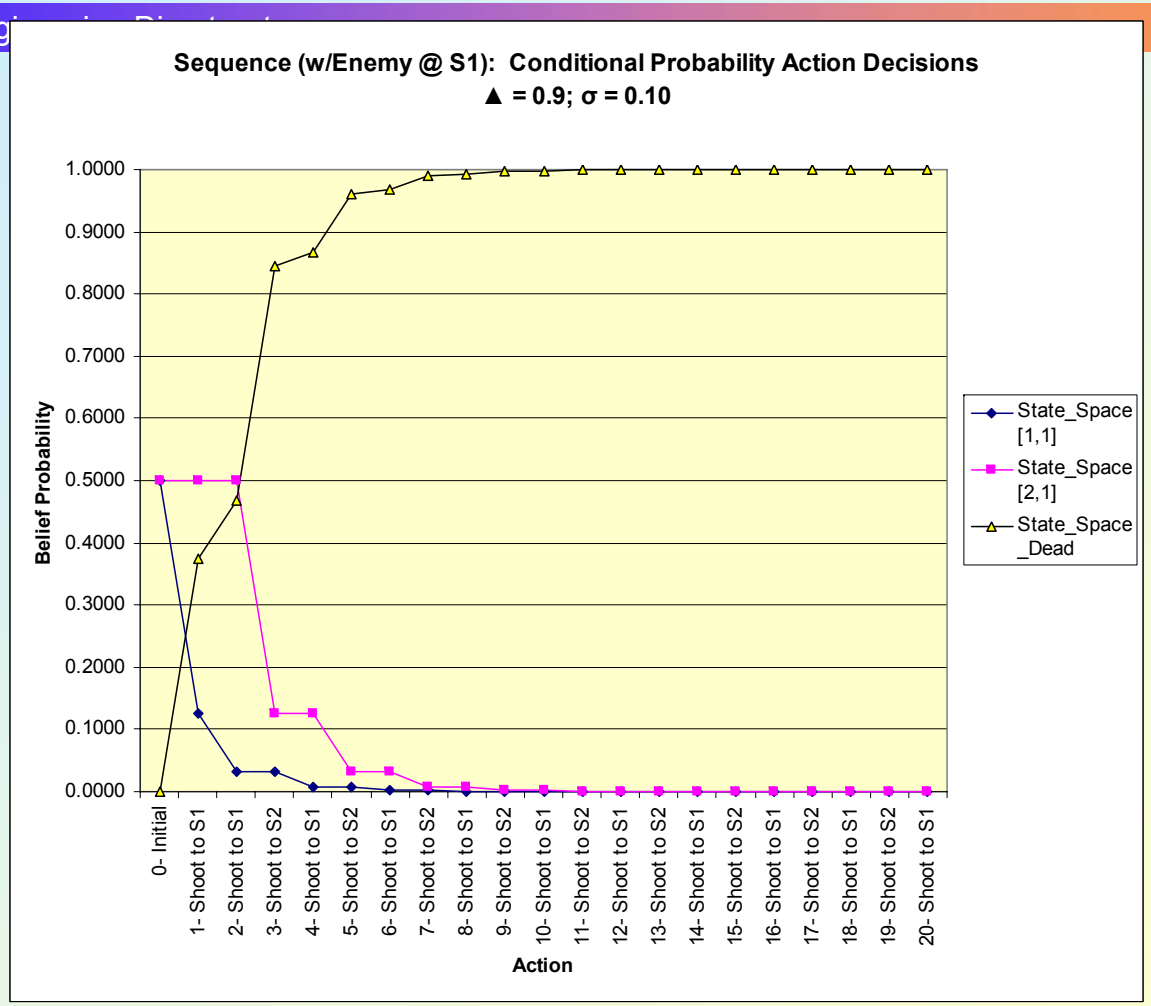

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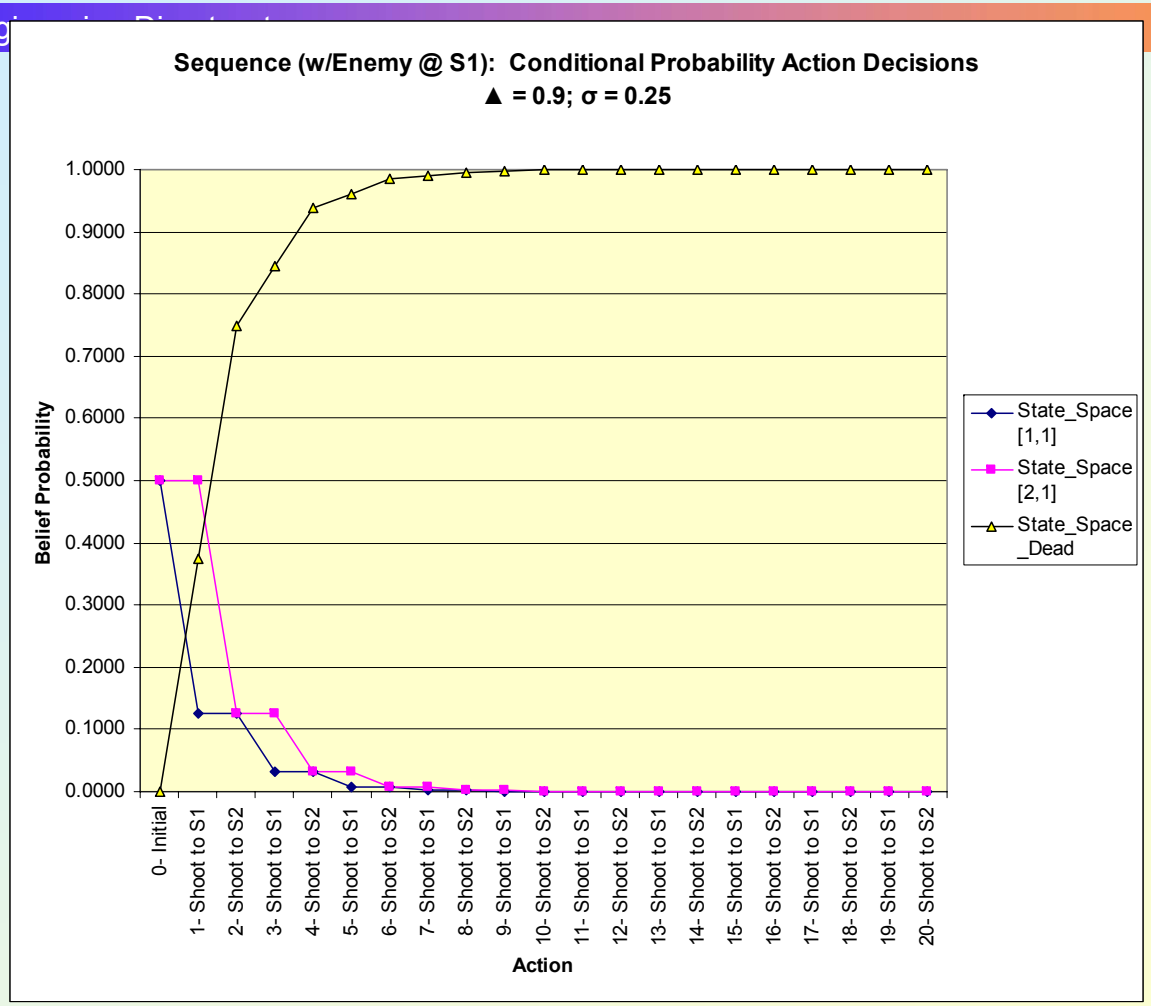

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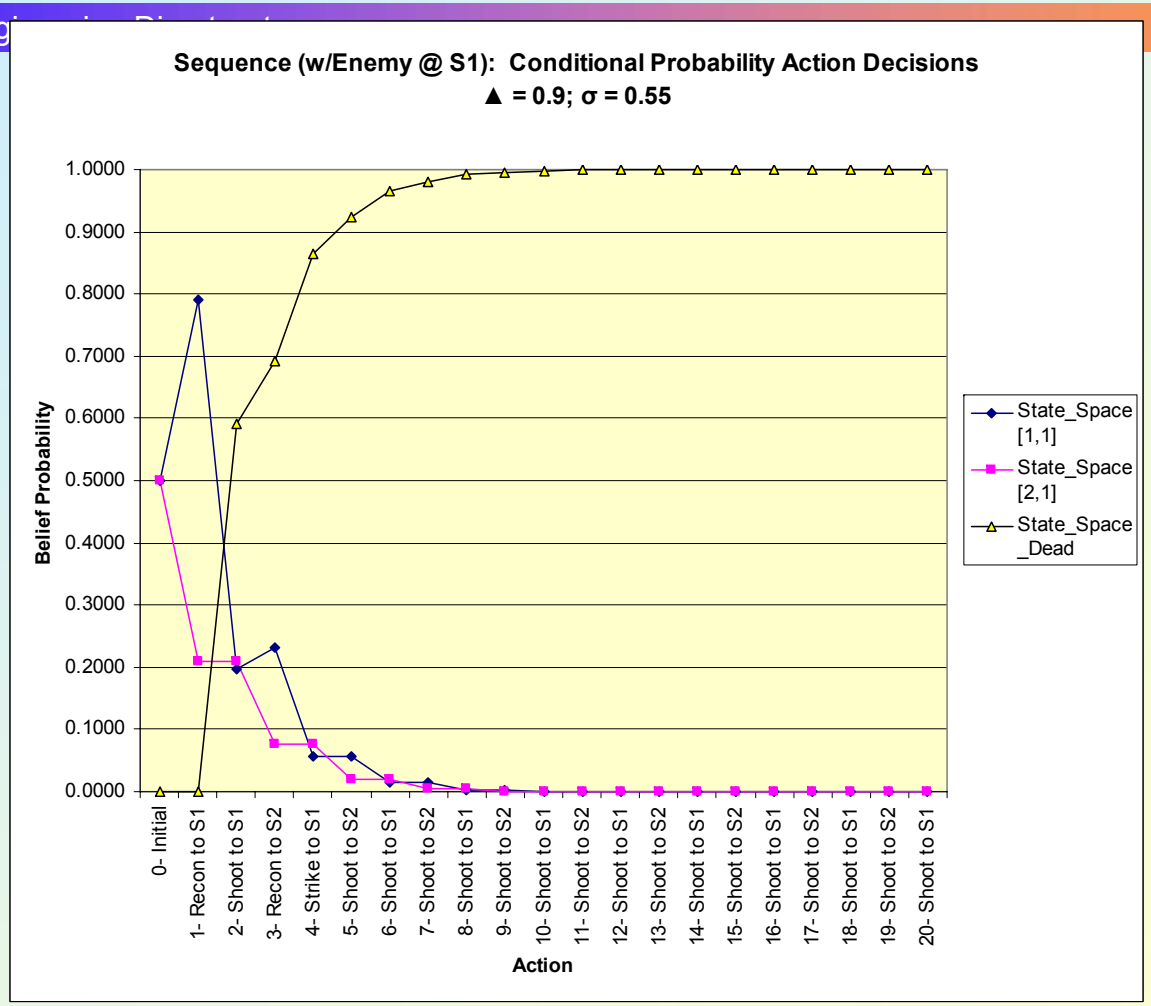

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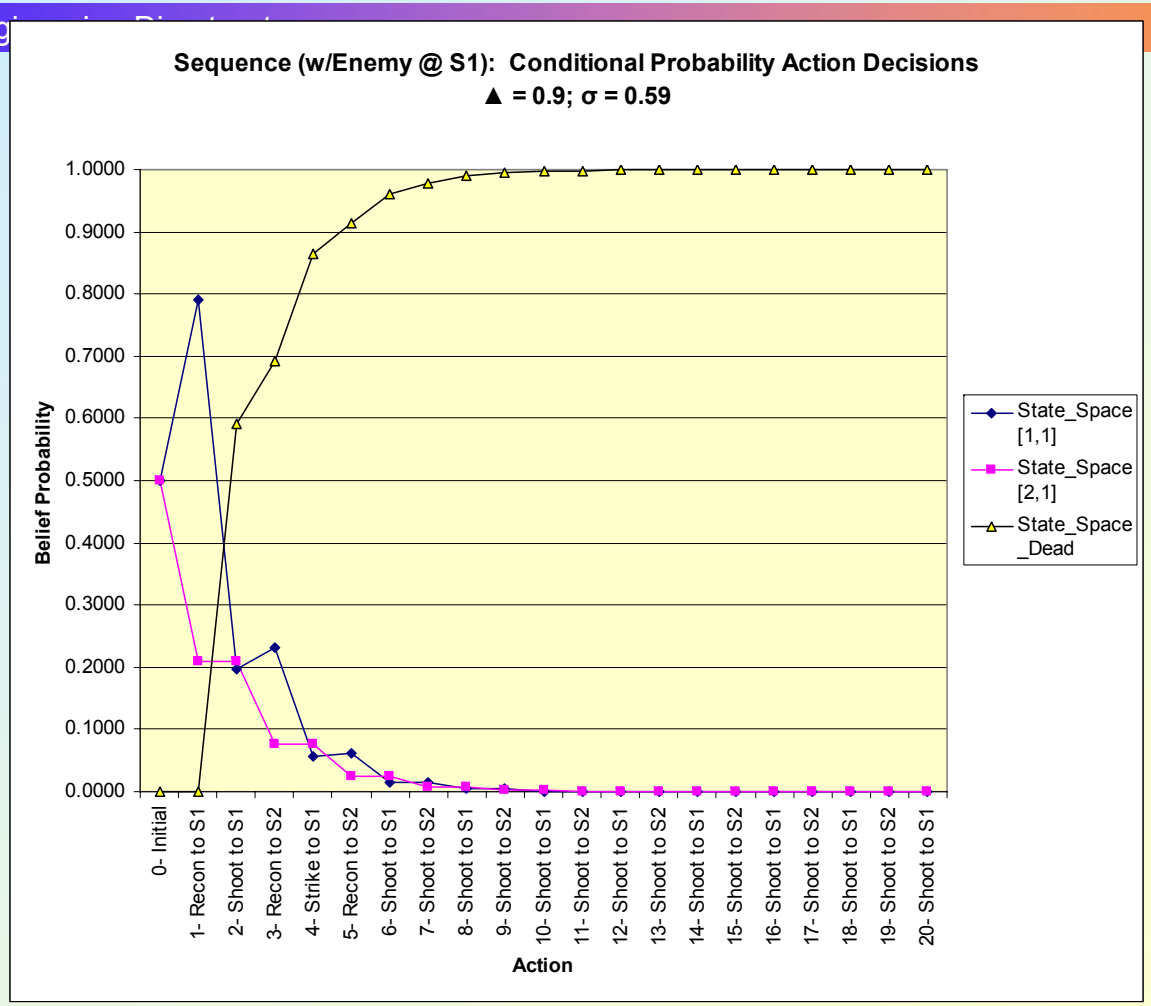

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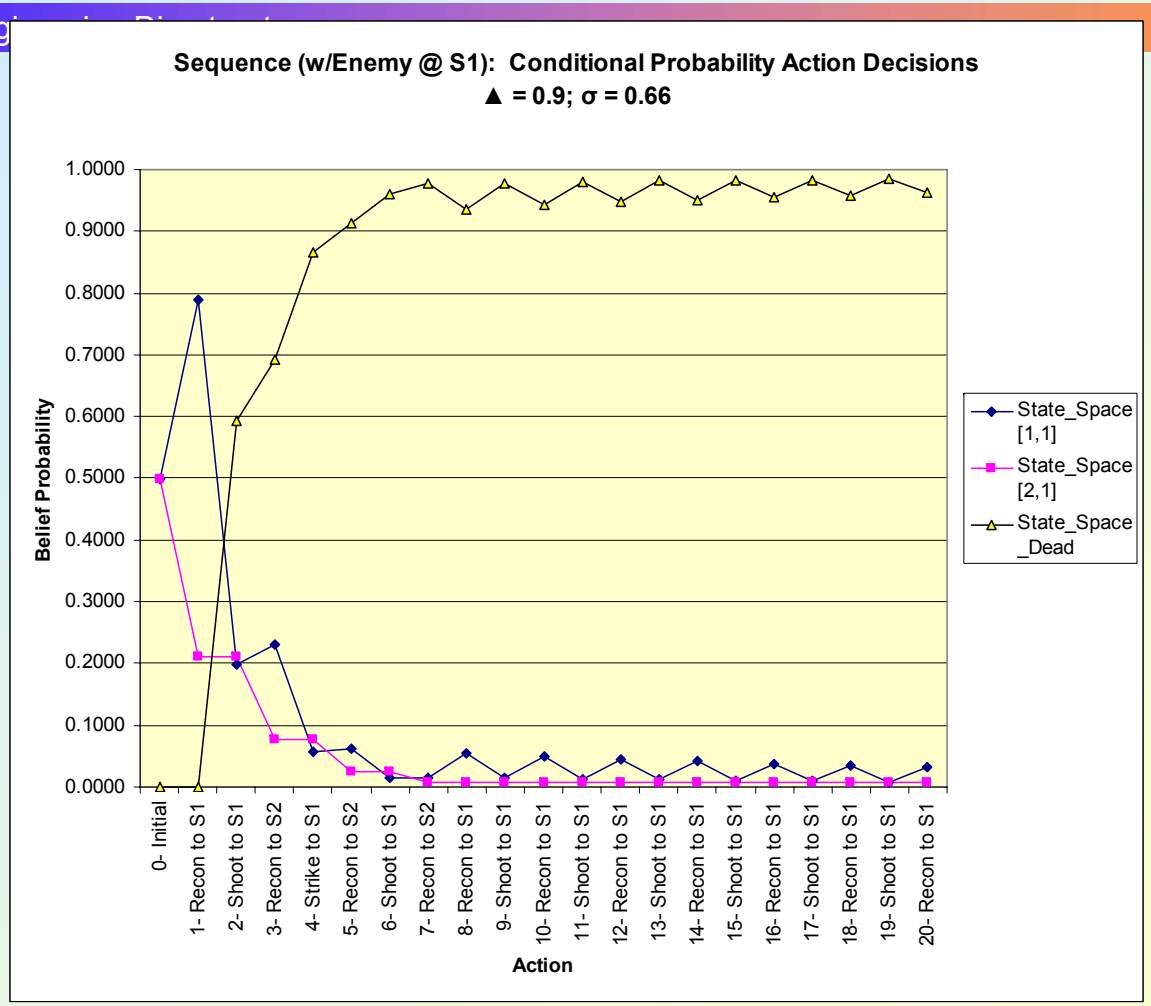

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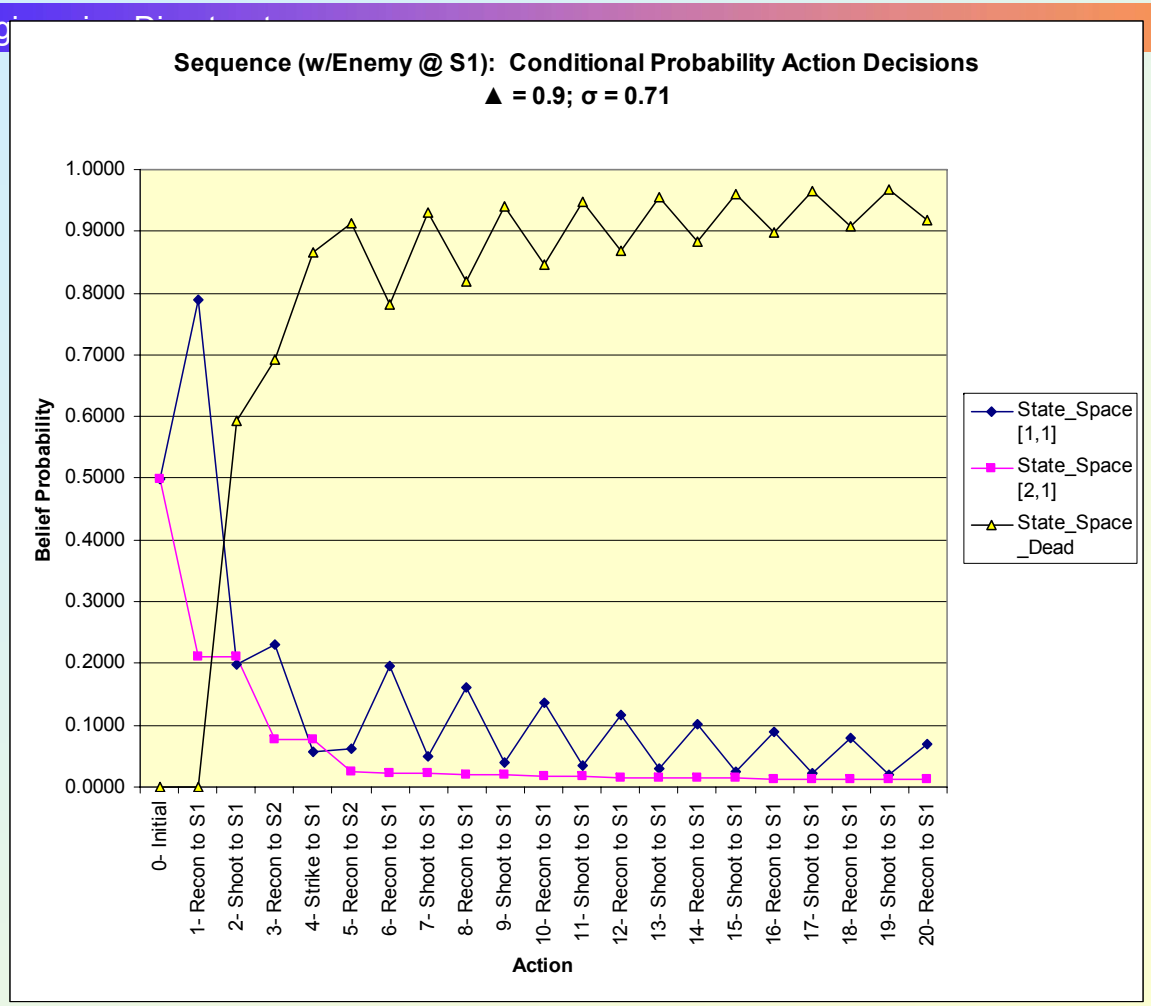

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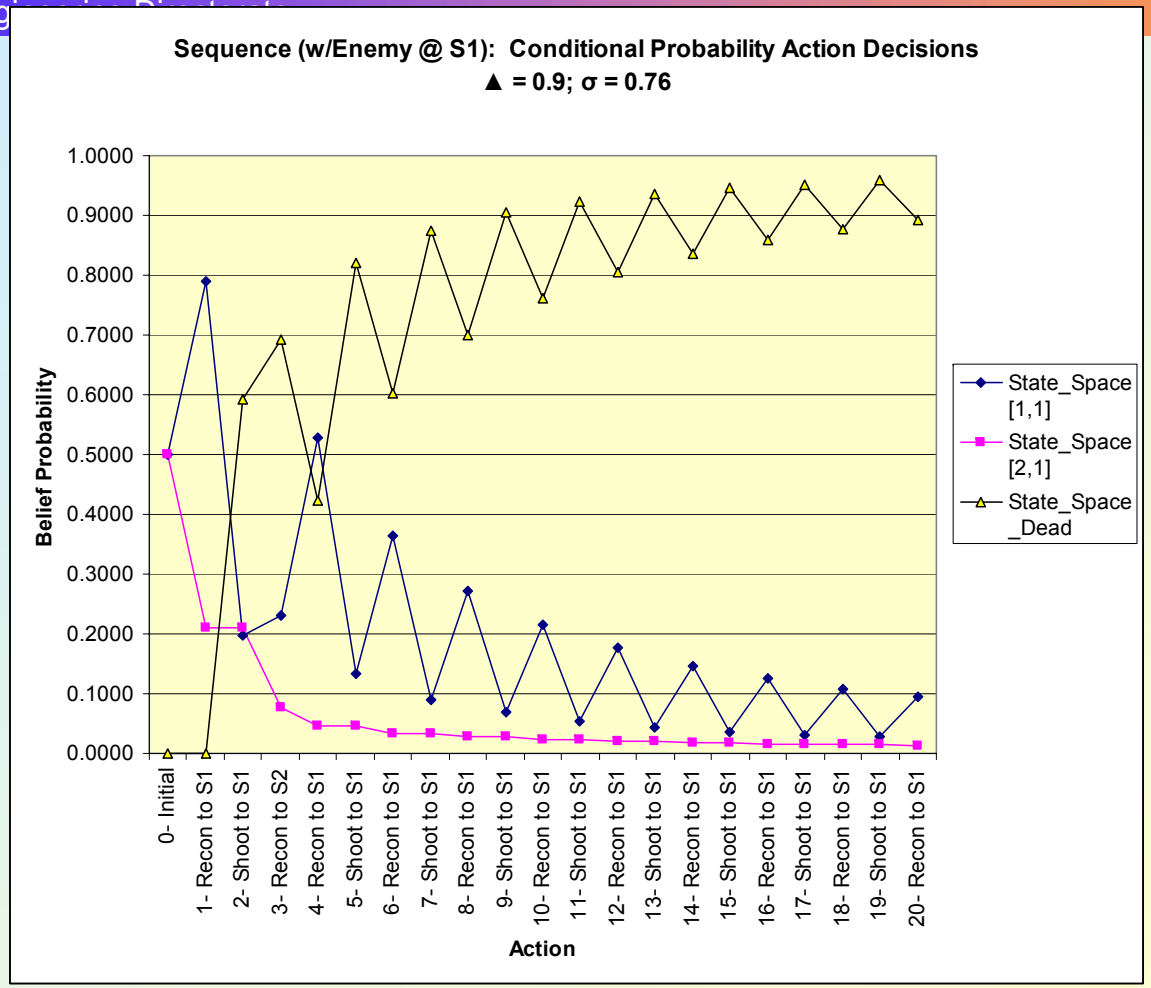

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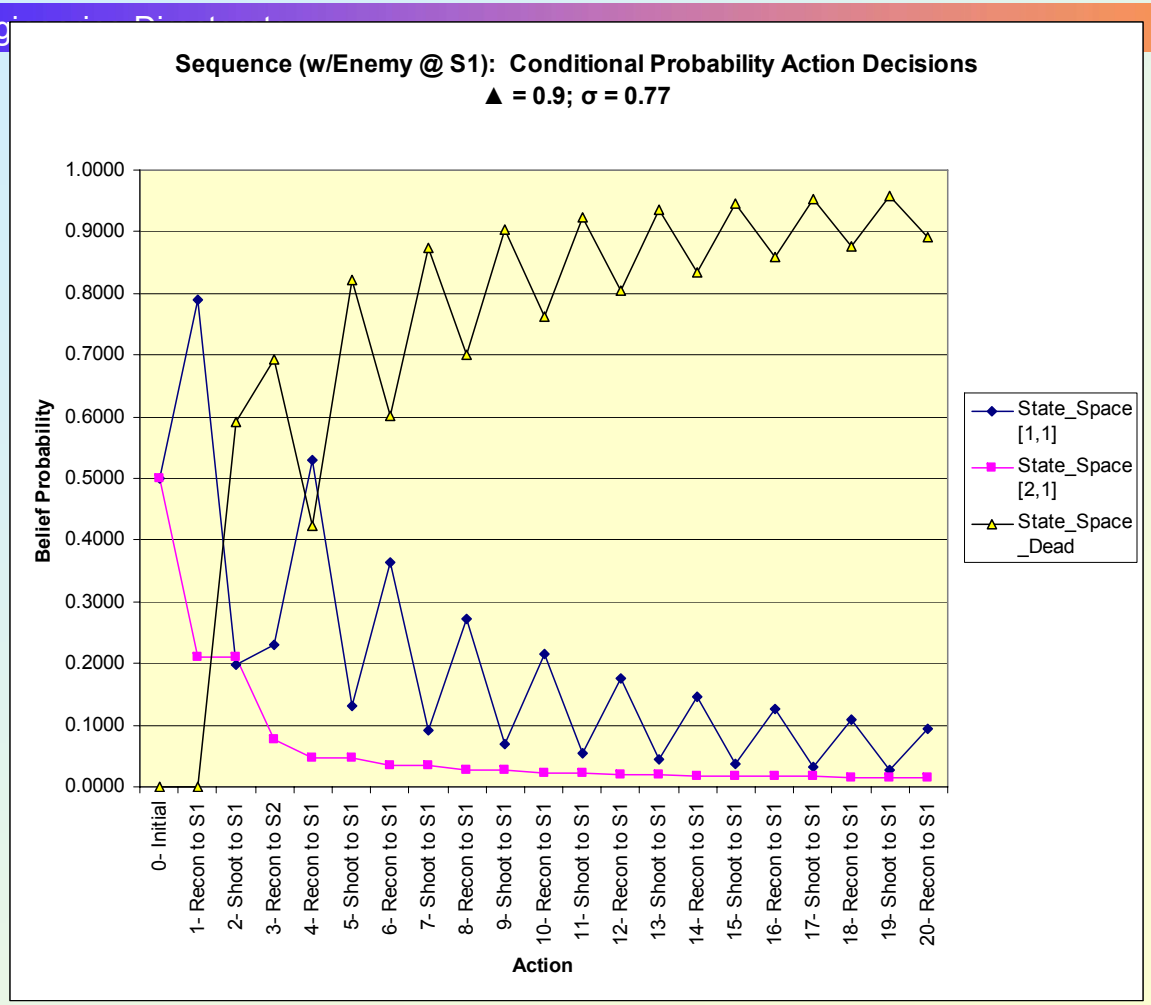

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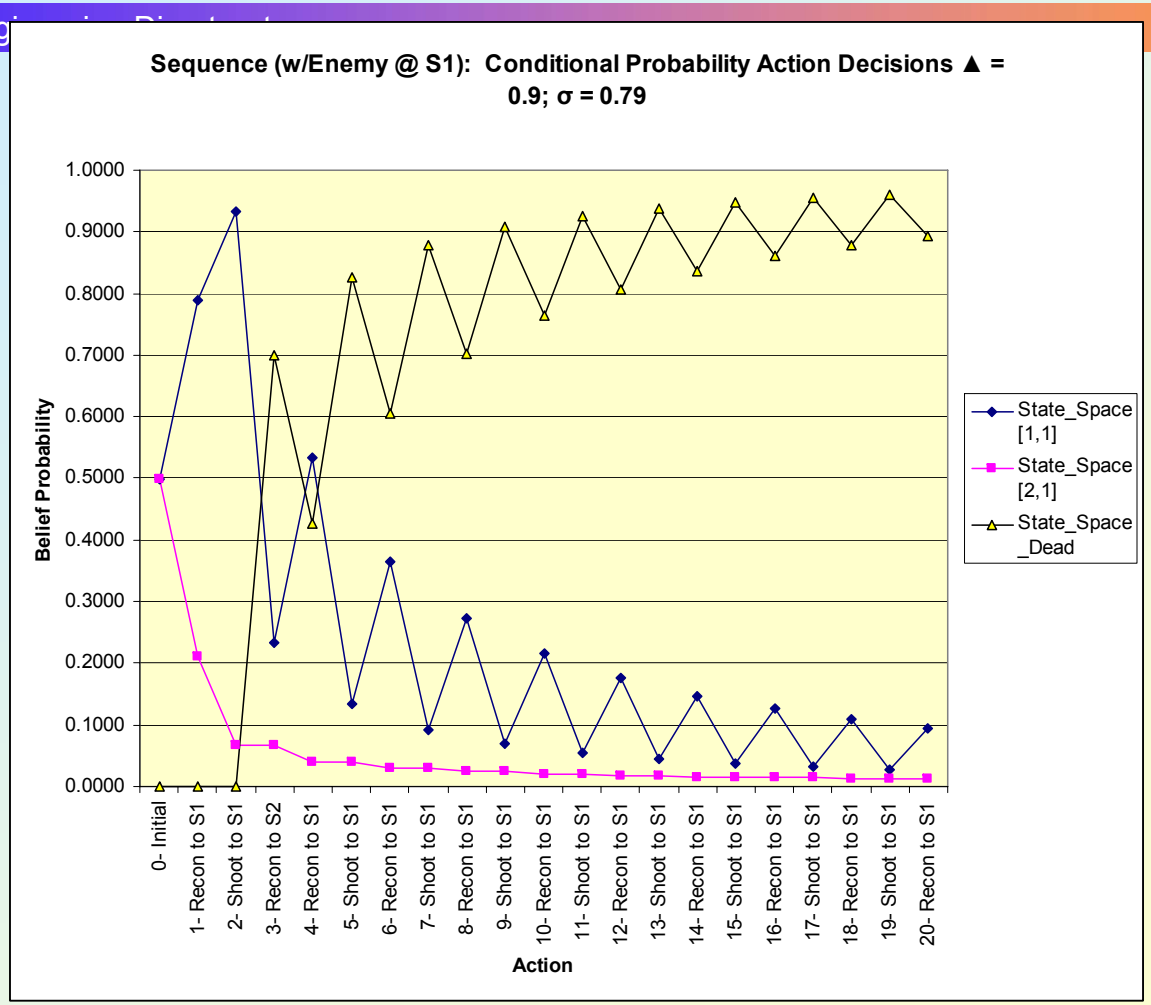

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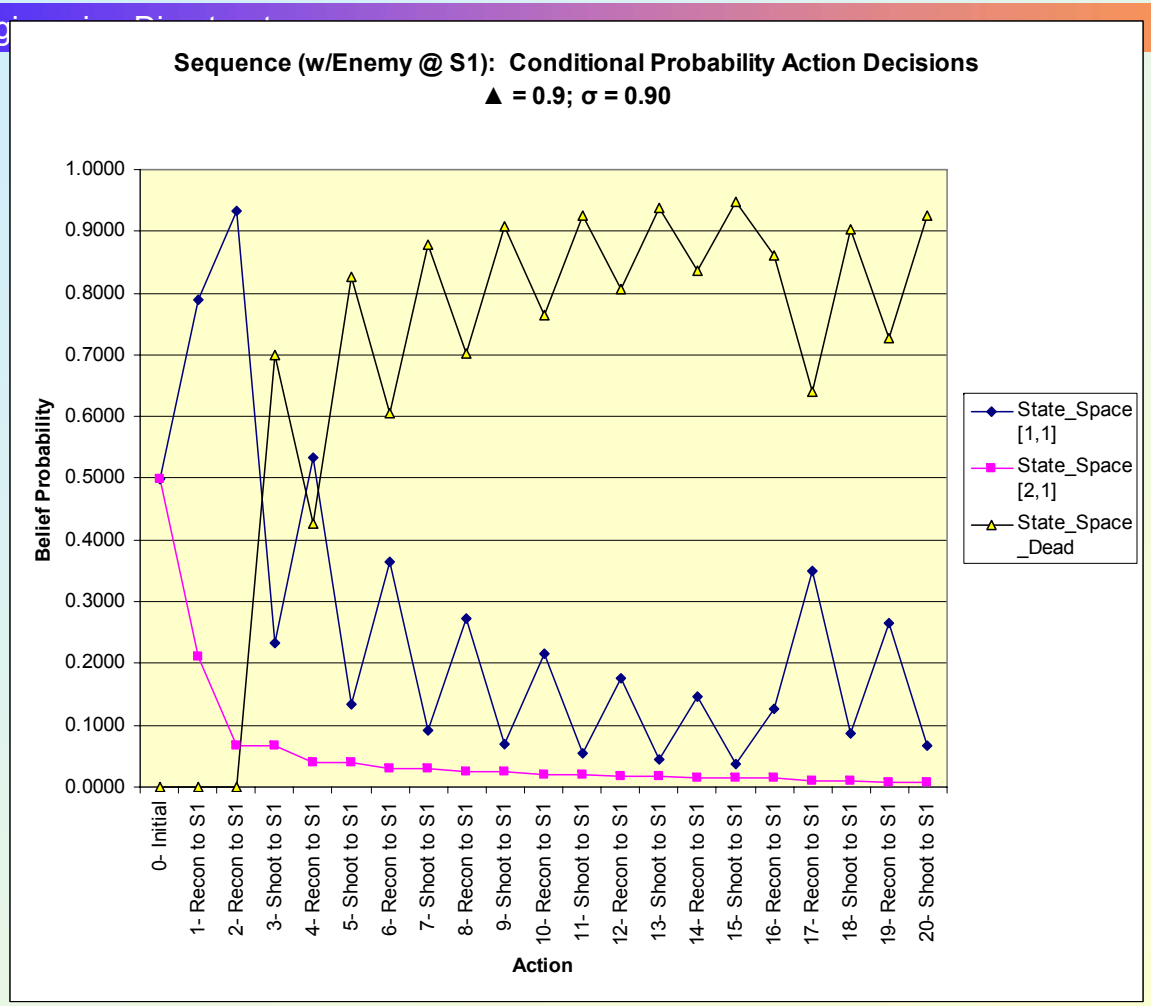

Action Decision Sequence by σ

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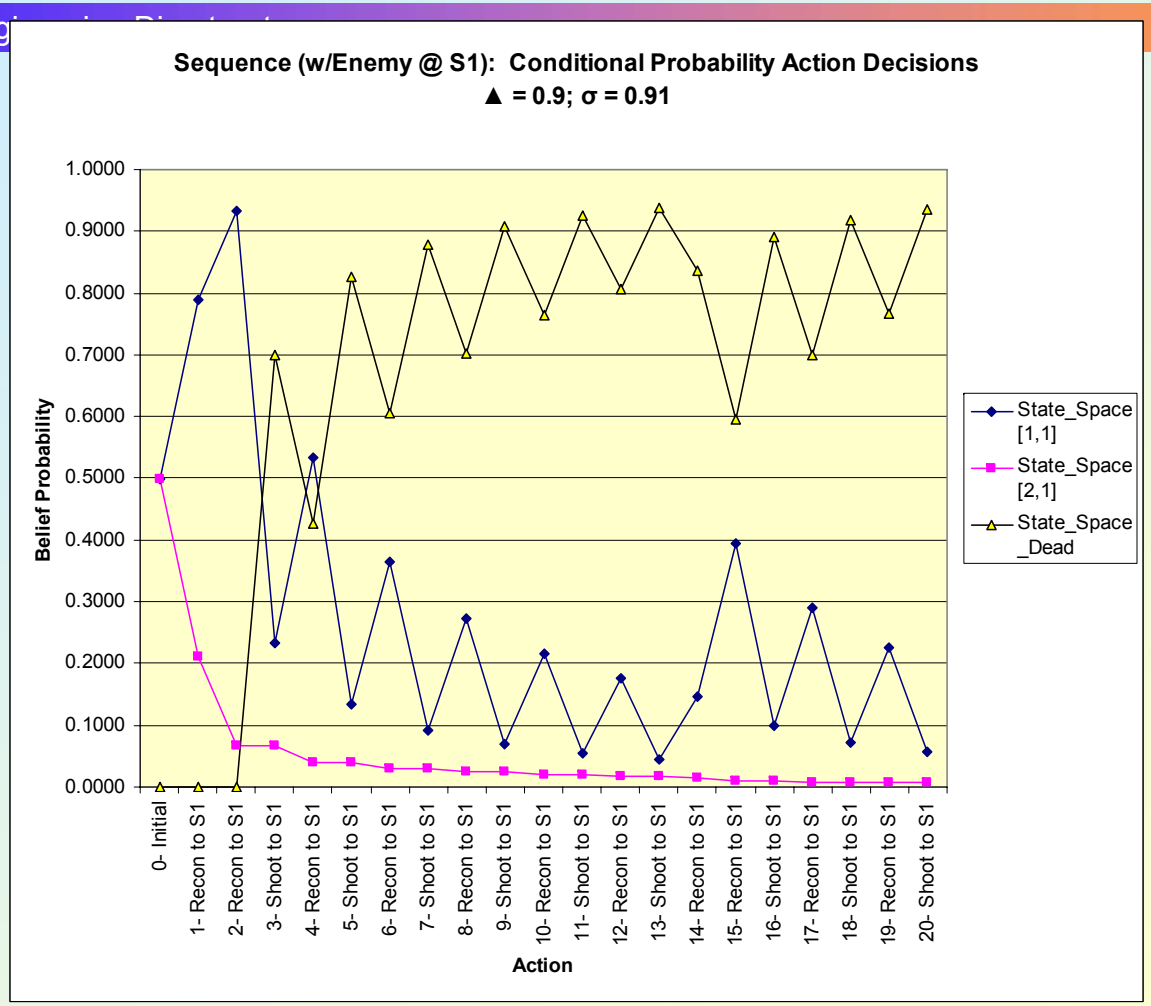

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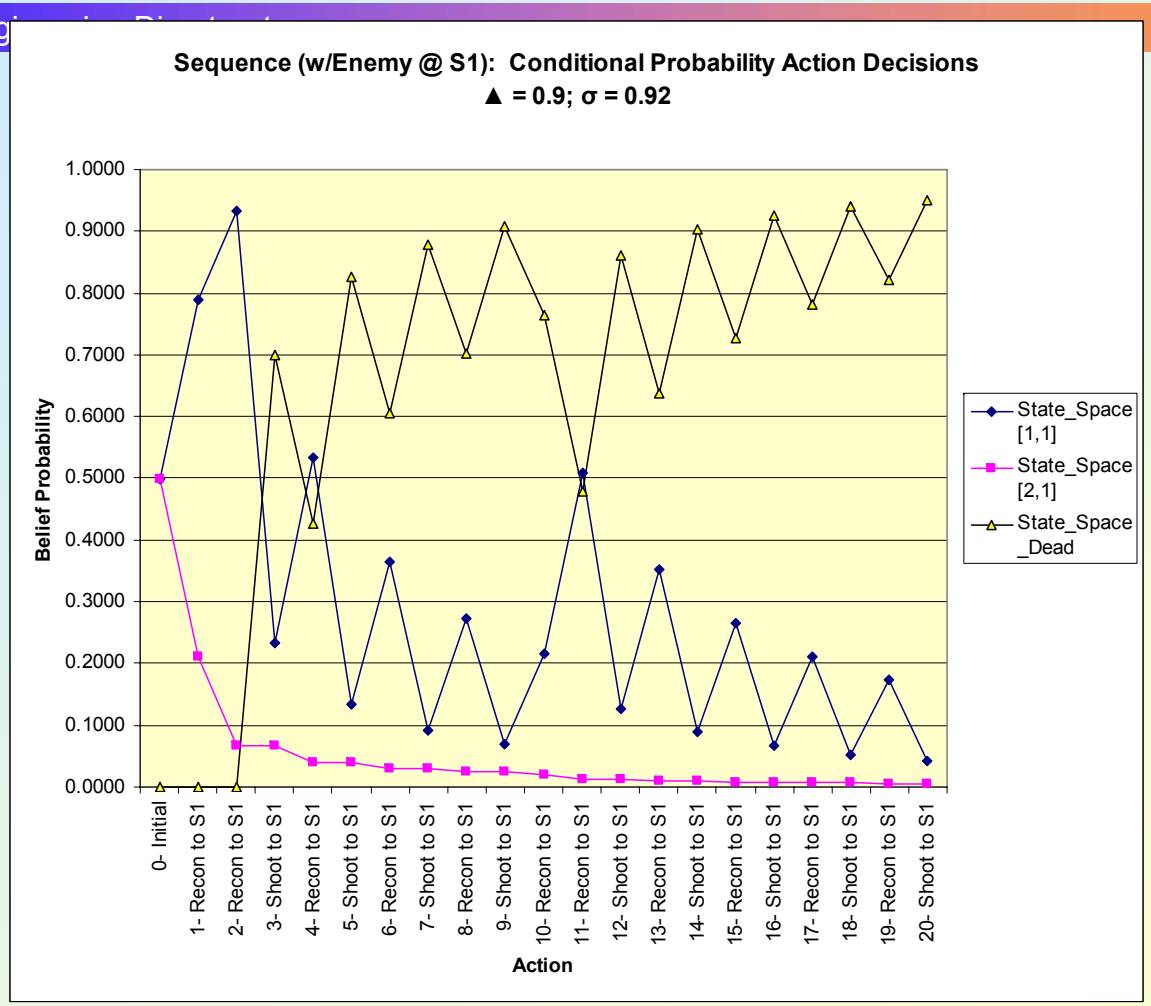

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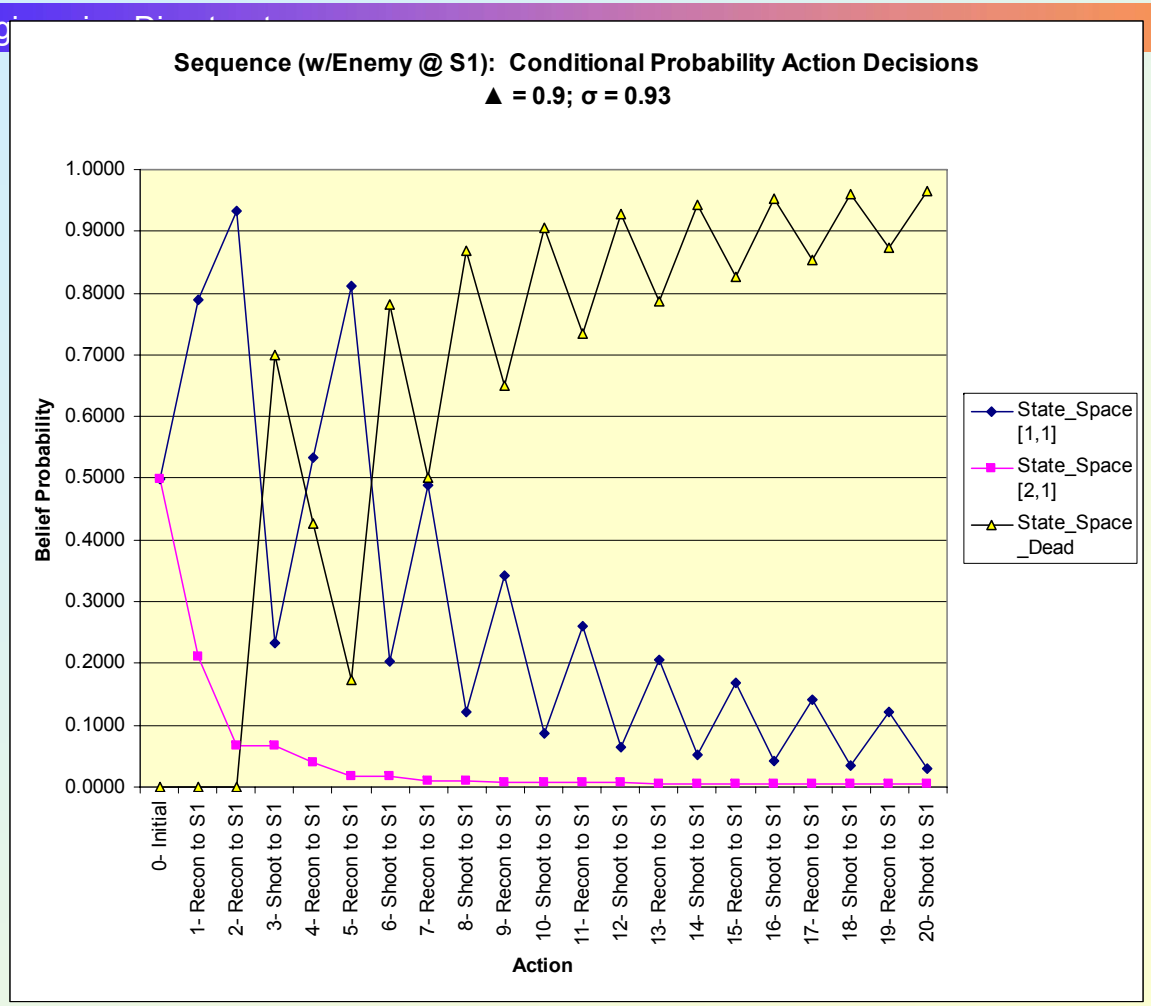

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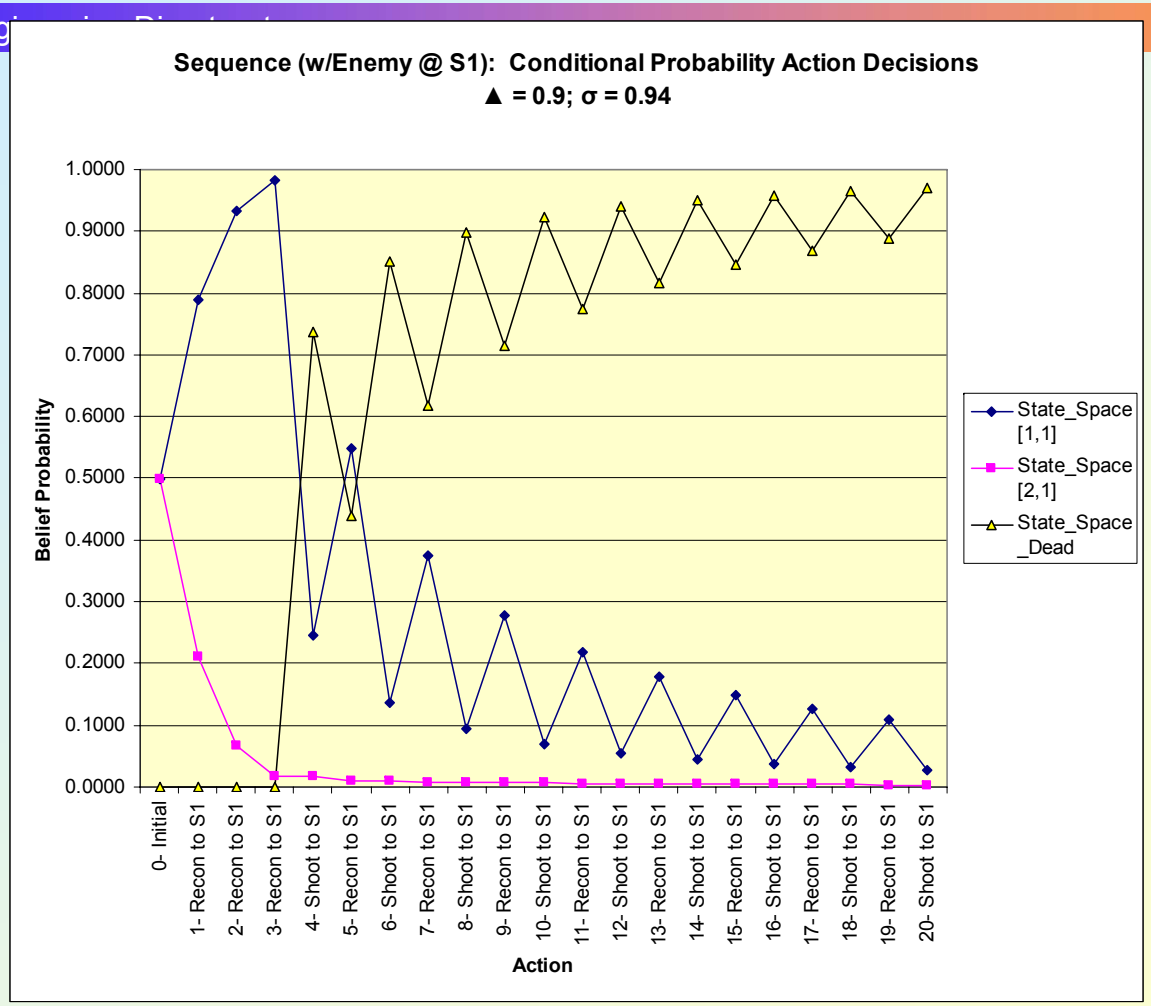

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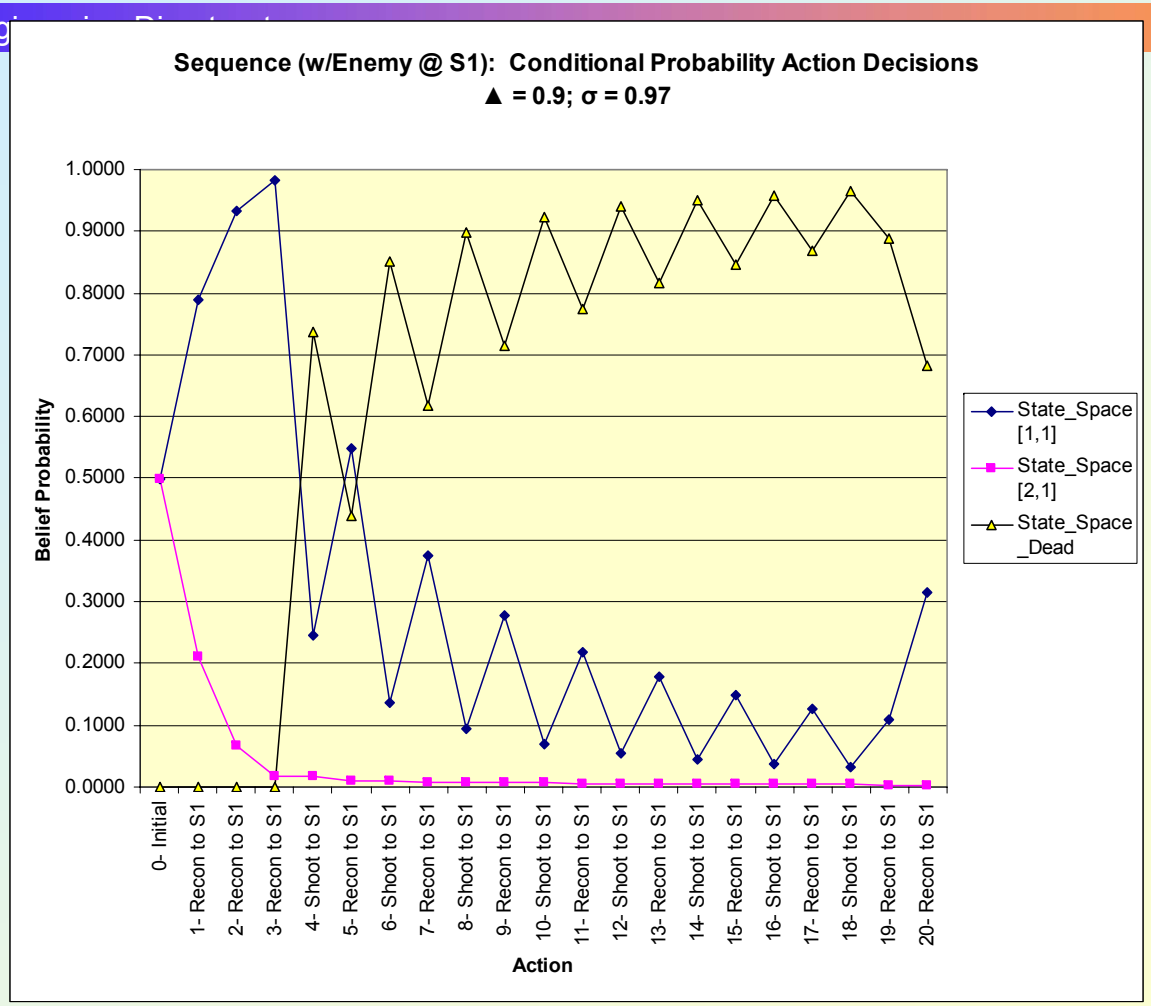

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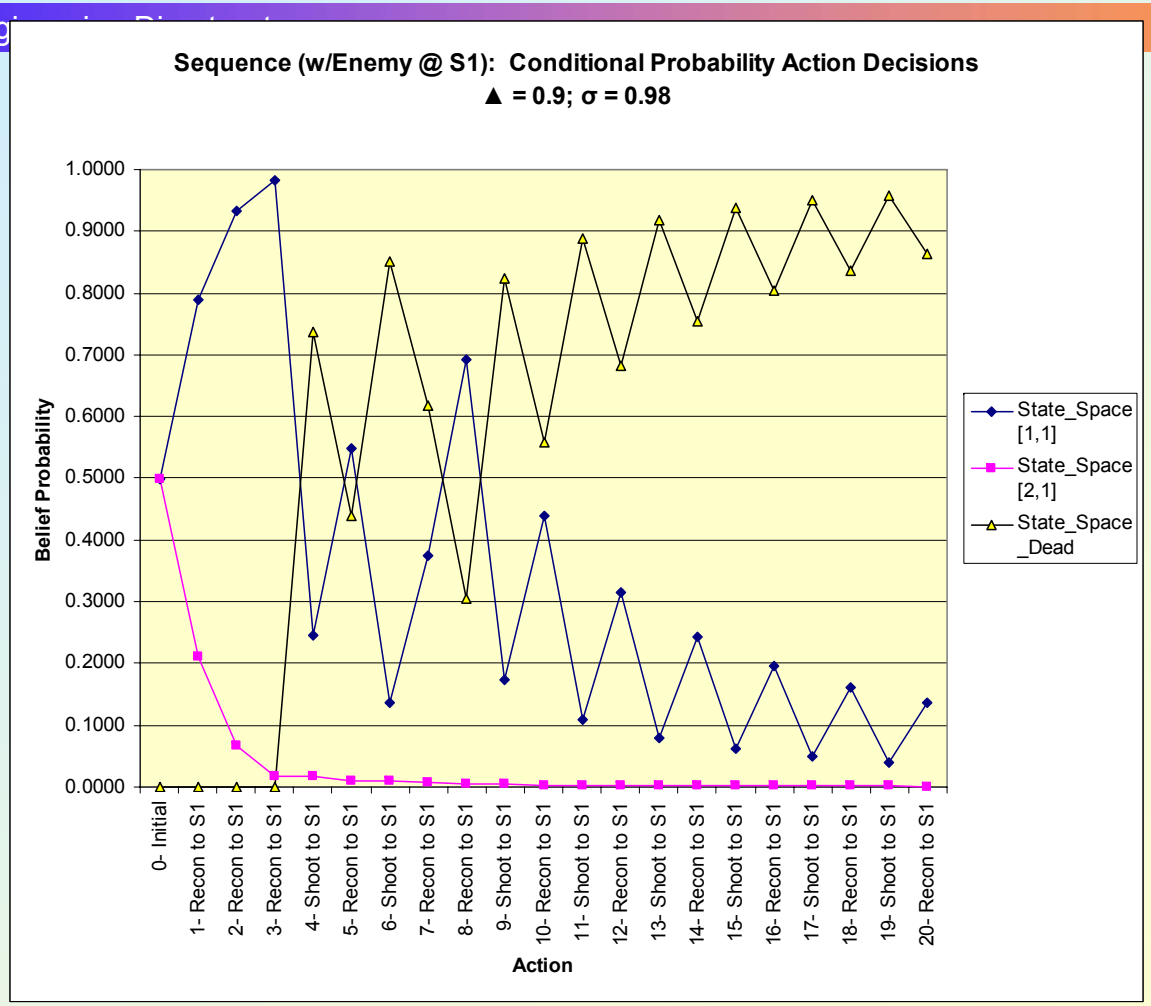

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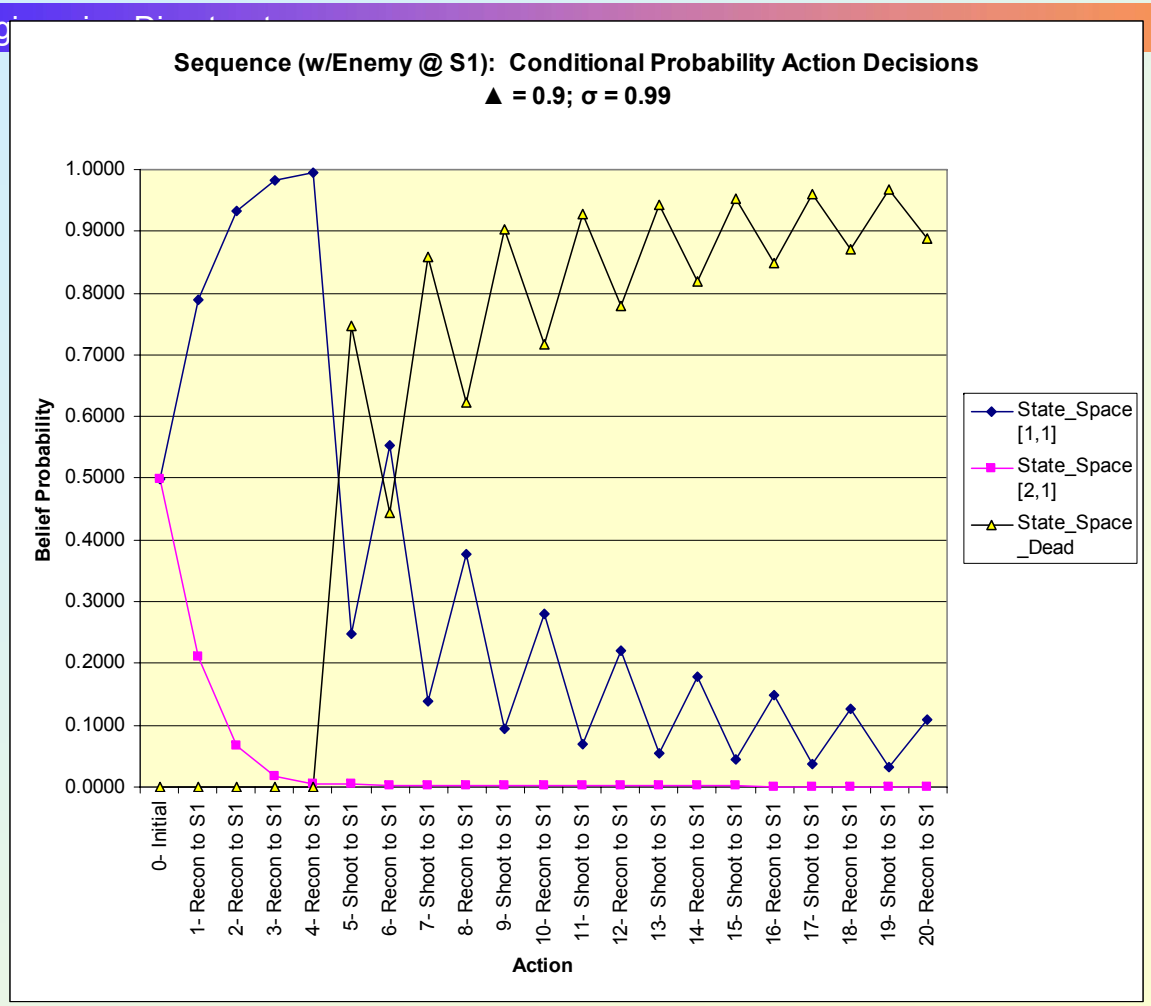

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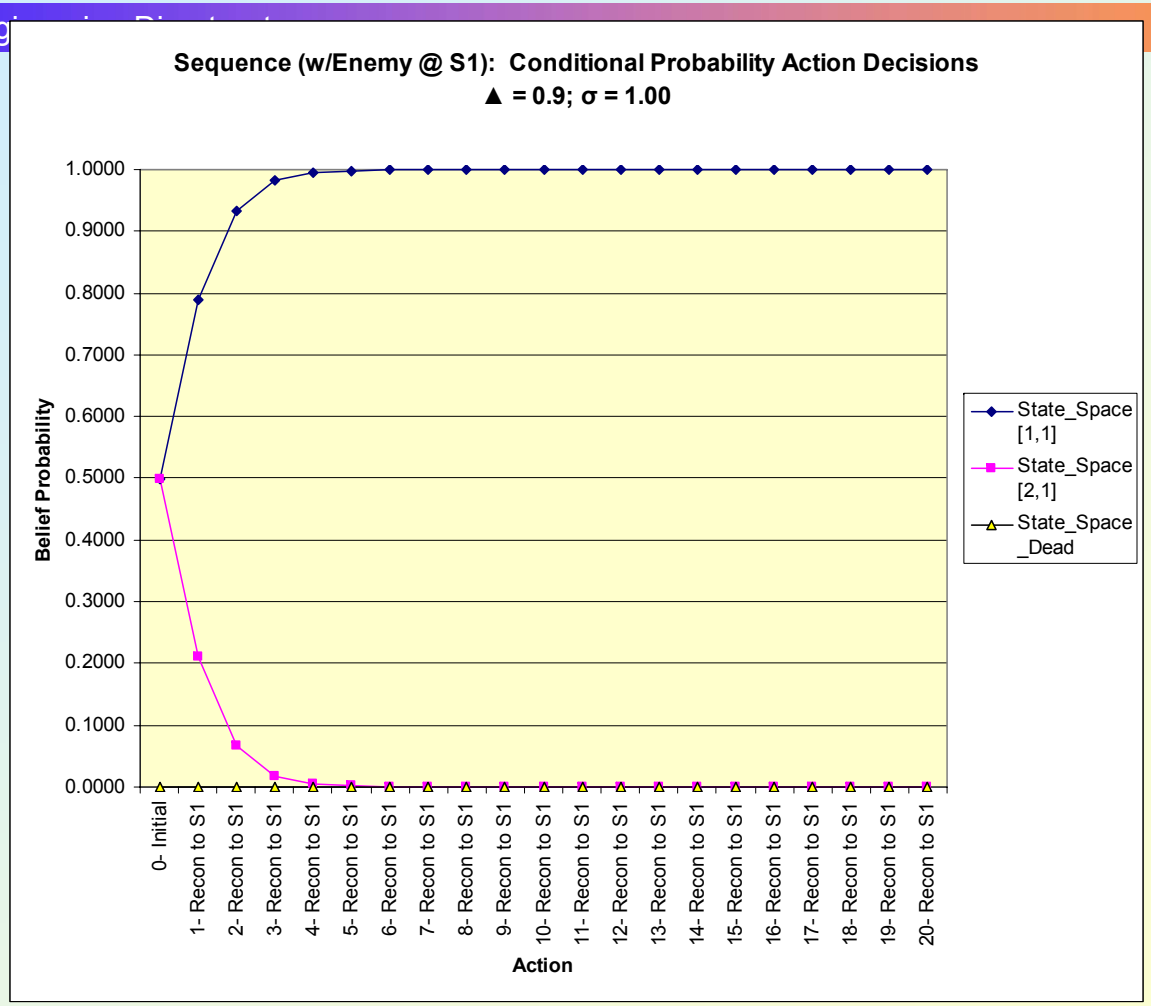

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