Information and Resource Sharing in Reinforcement Learning Agents Dealing with Risk

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***Abstract*—Risk aversion, which emerges as an inherent consequence of reinforcement learning, is potentially beneficial or harmful depending on circumstances. Risk aversion may help an agent to avoid negative outcomes it cannot afford or may lead to inefficient behavior through excessive risk premium payouts. Here we investigate knowledge and/or resource sharing as mechanisms for dealing with risk aversion among a group of homogeneous reinforcement learning agents. We find that ...**

I. Introduction

Uncertainty complicates decision making. When an agent needs to decide between two options, one of which has ...

Consider an reinforcement-learning agent that needs to repeatedly select between two options in order to try to maximize its acculated reward over time. The returned reward values of the options are sampled from probability distributions that are unknown to the agent. Moreover, the rewards are resources that the agent needs in order to survive—the agent uses resources as well as accumulates them; if the agent's resource level falls too low, it does not survive.

Now consider a homogeneous collection of such agents that are able to share information and/or resources with one another. How would ...

In economics, a simple, elegant, and well accepted definition of *risk* is noise in the values of expected outcomes. More formally, given three random variables X, Y, and Z, Y is said to be *riskier* than X iff $Y \sim X + Z$ (Y has the same distrution as $X+Z$) and $E(Z|X) = 0$ for all X (the expected value of Z given X is 0 with probability 1) [1]. An agent, then, is ceteris paribus *risk averse* if it prefers a less risky option to a more risky one, *risk seeking* if it prefers a more risky option to a less risky one, or *risk neutral* if riskiness does not influence its selection behavior.

Given two otherwise identical options, a deterministic risk-averse agent would always select the less risky option over the more risky one, whereas a probabilistic risk-averse agent would select the less risky option with greater than a 50% probability. However, factors beyond riskiness typically influence agent behavior, including and particularly expected value. If the expected value of the more risky option is greater than the expected value of the less risky option, even a risk-averse agent may prefer the riskier option.

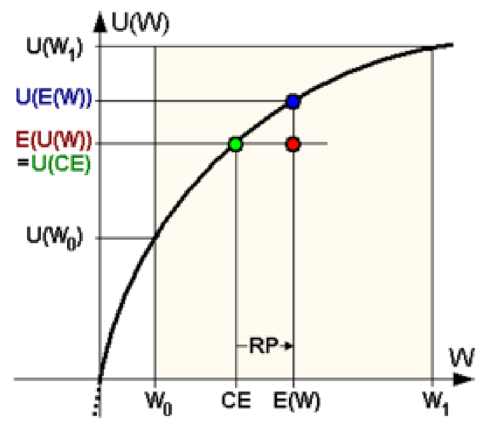

Fig. 1. Risk Aversion Utility Function Figure from Wikipedia. PLACEHOLDER ONLY!

Risk premium is the difference between expected values of a risky option and a risk-free (certain) option required to cause the risk-averse agent to have no preference between the options; if the difference is less than the risk premium value, the agent will prefer the risk-free option whereas if the difference is greater than the risk premium, the agent will prefer the risky option. It is referred to as a "premium" as it can be thought of as the amount the agent is willing to pay out to remove the risk from it's selection. The value of the risk premium can be used as a measure of an agent's risk aversion in a given circumstance.

Risk aversion has typically been explained in economics by reference to an agent's *utility function* U which maps the objective value of an outcome to a subjective valuation of that outcome. If the utility function is increasing and concave downward as shown in Figure 1, it exhibits dimenishing returns–for example, having objectively twice as much of a resource does not provide twice the utility, for example.

II. Hypotheses

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III. Approach

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IV. Experiments

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V. Results

[TODO]

Change "preference" terminology to selection.

Looking first at the 100-100 environment, for each knowledge-sharing population we see a broad range of values, centered at 0.5 and ranging mostly between 0.3 and 0.7 and occasionally extending out close to 0.2 at the low end up to 0.8 at the high end, with these extreme values appearing and dissappearing rapidly.

[TODO] Need to calculate mean and standard deviation for this. Also need to calculate linear regression. For knowledge-sharing cases, let's do this for time steps 0-10000. For individual-knowledge cases, let's do this for time steps 2000-10000. Also, median value would also be good to have.

VI. Discussion

A. Selection of Option A

Looking at the frequency with which agents select Option A in the individual-knowledge cases in the 100-100 environment, the agents in these populations quickly shift from their initial neutral selection behaviors to much more frequently selecting the safe option, with approximately 75% of the agents selecting the safe option at any given point after time step 500 or so.

This confirms what has been been both theoretically proven and empirically demonstrated elsewhere—that individuals that learn through reinforcement will act risk averse even when they have no explicit utility function [2].

In contrast, for the knowledge-sharing treatments in the 100-100 environment, there is, on average, no selection preference apparent for either option. Instead, at any given time a population might show a strong selection bias for one option or the other, with perhaps as much as 80% of a population selecting a particular option but these values are quite transient and, on average, 50% of the population selects either option, meaning that the knowledge-sharing agents exhibit no risk aversion.

These results strongly support Hypothesis H_1, that individuals that share knowledge will show substantially less risk aversion than those that learn individually.

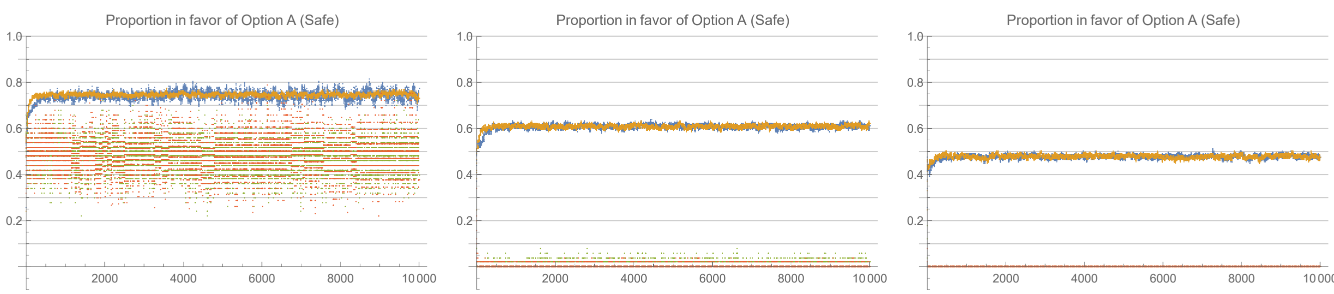
The greater variability in the selection frequency shown by the knowledge-sharing populations might at first seem counter intuitive. Shouldn't sharing knowledge enable the agents to have a more consistent view of the world and therefore make more consistent choices over time? However, it should be noted that each agent's selection algorithm causes an individual with no preference to select at random while an agent with a very strong preference will almost always select its preferred option. Because knowledge-sharing allows the agents to recognize that both options have equal expected values, they exhibit no preference and select at random—hence the variability shown. In constrast, the individual-knowledge agents are biased due to learning individually via reinforcement and hence their likelihood of choosing the risky option is greatly decreased.

Of course, there is some variability in the selections exhibited by the individual-knowledge populations, with the individual-resource populations' selections generally ranging between 60% to 80% of agents selecting Option A and the resource-sharing populations showing noticably less variability than that. The resource-sharing populations also reach their selection bias noticably more quickly.

The difference in variability between the individual-knowledge populations that don't share resources and those that do, as well as their different rates in reaching their selection biases, can be attributed to survival. Because far fewer individuals survive when resources are not shared, there are fewer individuals in those populations over which to average the selections, which results in greater variability. As for the

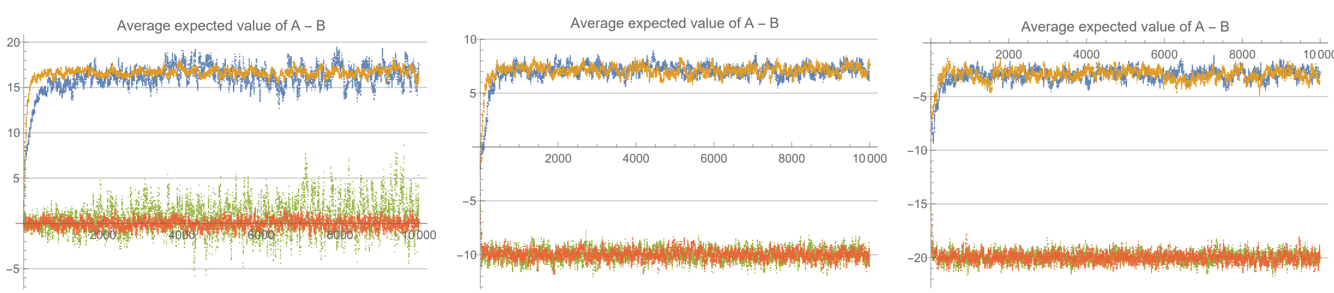
TABLE I
RESULTS. ANOVA P-VALUES OF SELECTED COMPARISONS.

		100-100 algorithm	100-100 interaction	100-110 algorithm	100-110 interaction	100-120 algorithm	100-120 interaction
Selection	IKIR vs IKSR						
	SKIR vs SKSR						
A−B	IKIR vs IKSR						
	SKIR vs SKSR						
Population	IKSR vs SKSR						
	IKIR vs SKIR						
Resources per Capita	IKIR vs SKIR			—	—	—	—
	SKIR vs SKSR			—	—	—	—
	SKIR vs SKSR	—	—				
	IKIR vs IKSR	—	—				
Total Resources	IKIR vs IKSR			—	—	—	—
	IKIR vs SKIR			—	—	—	—
	IKIR vs SKSR			—	—	—	—
	IKSR vs SKIR					—	—
	IKSR vs SKSR			—	—	—	—
	SKIR vs SKSR			—	—	—	—



(a) 100-100 (b) 100-110 (c) 100-120

Fig. 2. Proportion of the population selecting Option A.

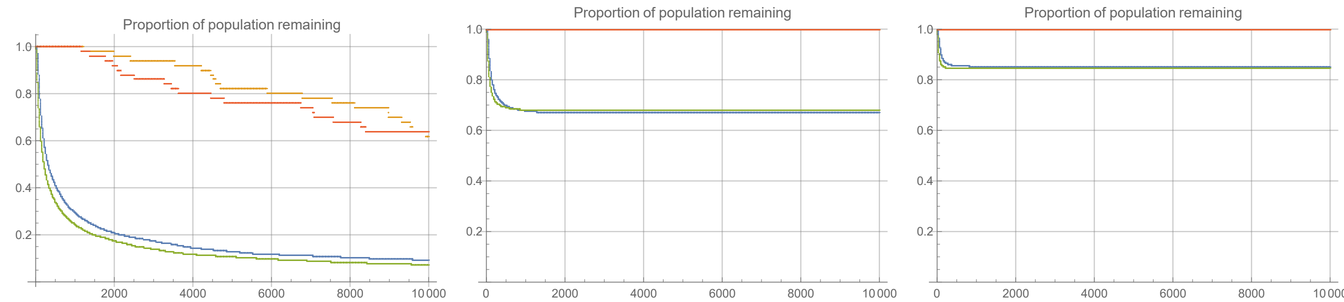


(a) 100-100 (b) 100-110 (c) 100-120

Fig. 3. Value A-B

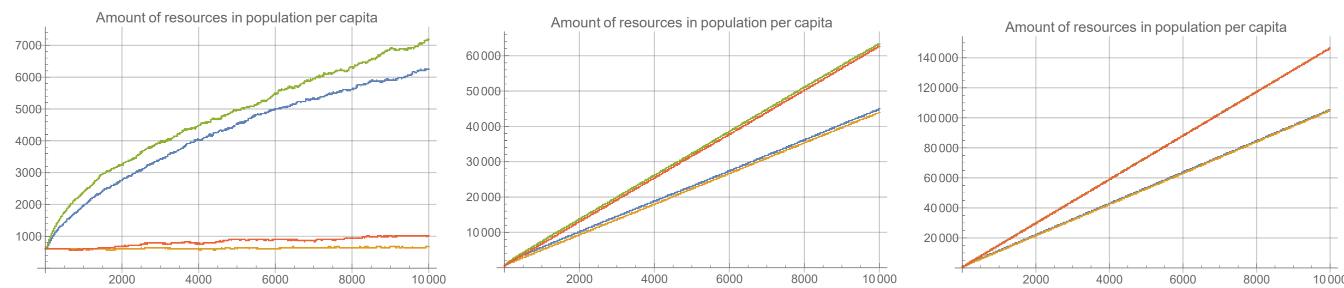
rate of reaching selection bias, individuals that should show the strongest bias against Option B are those that recieved a 0 reward from it several times in succession when selecting it. However, these same individuals are the ones that are removed from the population if there is no resource sharing. So, when the next time step arrives and those individuals would likely select Option A, they are no longer in the population. Instead, those agents still in the population are those that have not had such negative experiences with Option B, so they are less biased against it. In contrast, when resources are shared, individuals that recieved a 0 reward from Option B several times in succession when selecting it will nonetheless survive and they will likely select Option A, pulling their population average more rapidly toward selection of A.

From the 100-100 environment to the 100-110 environment, there are two substantial changes for the knowledge-sharing



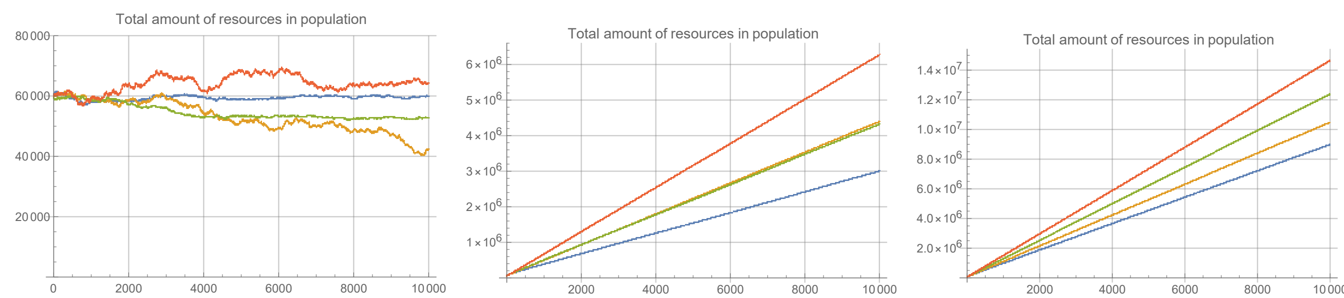
(a) 100-100 (b) 100-110 (c) 100-120

Fig. 4. Percent of Population Remaining



(a) 100-100 (b) 100-110 (c) 100-120

Fig. 5. Resources per Capita



(a) 100-100 (b) 100-110 (c) 100-120

Fig. 6. Total Resources

treatments. First, rather than selecting Option A on average 50% of the time (showing no preference for either option), the selection rate for Option A has dropped to near 0%. Second, the variability has been drastically reduced. After the first few time steps, the selection rate rarely ranges above 0.05%. In other words, from virtually no selection bias with great variability in the 100-100 environment, the knowledge-sharing agents here overwhelmingly select Option B—the risky but higher-rewarding option.

The changes for the individual-knowledge populations are also substantial, though less dramatic. From 75% preference for the safe option in Environment 100-100, the individual-knowledge agents here show about a 60% preference for that option and the variability for the individual-resource populations has dropped noticably.

These results also strongly support Hypothesis H_1. The knowledge-sharing agents show very little, if any, risk aversion—the vast majority of them select Option B because it is the higher-rewarding option despite its greater risk. In contrast, the individual-knowledge agents still select Option A more than half the time despite its lower-reward because they are acting averse to its higher risk.

The trends from the 100-100 to the 100-110 environment continue into the 100-120 environment. Now the knowledge-sharing agents almost universally select the risky but higher-rewarding option and the rate at which the individual-knowledge agents select the safe option has fallen below 50%—the higher reward for Option B has, on average, slightly exceeded the risk premium they're willing to pay, so slightly more of them choose it despite its risk.

Again, these results strongly support Hypothesis H_1. While the individual-knowledge agents here choose Option A slightly less than half the time, this nonetheless lies in stark contrast to the knowledge-sharing agents that almost never choose this lower-rewarding option.

B. Average Expected Value

Looking at the differences in average expected value between Option A and Option B in the 100-100 environment, we see that the agents in the individual-knowledge populations quickly learn to undervalue Option B. From an initial belief that the options are equally rewarding (which happens to be true), individual learners conclude that Option A is worth on average roughly 17 resource units more than B, which is not accurate. This contrasts sharply with the knowledge-sharing agents that, for the most part, maintain an average expected value difference near the true expected value of 0.

This strongly supports Hypothesis H_2 which says that reinforcement learning using knowledge sharing allows agents to more accrately gauge expected value than does individual reinforcement learning.

Despite the much more accurate assessment of expected value among the knowledge-sharing populations, there is a trend over time among the individual-resource populations away from that accurate assessment and toward undervaluing Option B, as well as a trend toward greater variability in their assessments. These trends can be attributed to survival. Over time, more than 90% of these agents are eliminated, meaning that there are far fewer individuals sharing knowledge, which results in greater variance, and those agents that survived are likely to be from populations that undervalued B to a greater extent and therefore selected Option A more often. [[TODO: This explanation for increasingly undervaluing B seems bogus.]]

This trend toward greater variability and increasingly undervaluing Option B is also seen, though less dramatically for the individual-learning, individual-resource populations. The fact that this effect is muted in these populations can be attributed to fact that the learning rule ...

In the 100-110 environment, the agents in individual-knowledge populations again quickly learn to undervalue Option B, estimating an expected value around 7 resource units higher than for Option A, despite the fact that the expected value of Option A is actually 10 resource units lower. This is roughly the same 17 point spread between estimated expected value difference and actual expected value difference found in the 100-100 environment. Again, this contrasts sharply with the knowledge-sharing agents that maintain an average expected value difference of near the true expected value of -10.

Again, this strongly supports Hypothesis H_2—the knowledge-sharing agents have much more accurately gauged the expected values than have the individual-learning agents.

A substantial difference between the 100-100 environment and the 100-110 environment, however, does exist. In the 100-110 environment, agents in the individual-resource populations do not increasingly undervalue Option-B, nor do the variances within the populations increase over time. This is because far fewer of these agens are eliminated. In the 100-110 environment, more than 60% of the agents from these populations survive, on average, compared to less than 10% in the 100-100 environment.

In the 100-120 environment, the agents in the individual-knowledge populations yet again quickly learn to undervalue Option-B by approximately 17 resource units, on average. In this environment these agents now value Option B over Option A, rather than valuing A over B as they had previously, but only by about 3 units, whereas the true expected value of Option B is 20 units higher than that for Option A. Also, this yet again contrasts sharply with the knowledge-sharing agents that maintain an accurate average estimated value difference. Naturally, this yet again strongly supports Hypothesis H_2.

C. Survival

VII. Conclusions

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VIII. Future Work

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