Long-Range Planning and Behavioral Biases: A Computational Approach

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Including joint work with Manish Raghavan and Sigal Oren.

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Long-Range Planning

Growth in on-line systems where users and groups have long visible careers and set long-range goals.

- Reputation, promotion, status, individual achievement.
- On-line groups that create multi-step tasks and set timelines and deadlines.
Badges, Milestones, and Incentives

- **The Placement Problem:**
  Given a desired mixture of actions, how should one define milestones to (approximately) induce these actions?

- How do badges and milestones derive their value?
  Social / Motivational / Transactional?

Planning and Time-Inconsistency

Fundamental behavioral process: Making plans for the future.

- Plans can be multi-step.
- Natural model: agents chooses optimal sequence given costs and benefits.

What could go wrong?

- Costs and benefits are unknown, and/or genuinely changing over time.
- Time-inconsistency.
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Agent must ship a package sometime in next $n$ days.

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- Loss-of-use cost $x$ each day hasn’t been shipped.
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An optimization problem:

- If shipped on day $t$, cost is $c + tx$.
- Goal: $\min_{1 \leq t \leq n} c + tx$.
- Optimized at $t = 1$. 
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In Akerlof’s story, he was the agent, and he procrastinated:
- Each day he planned that he’d do it tomorrow.
- Effect: waiting until day \( n \), when it must be shipped, and doing it then, at a significantly higher cumulative cost.
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A model based on present bias [Akerlof 91; cf. Strotz 55, Pollak 68]
- Costs incurred today are more salient: raised by factor \( b > 1 \).

On day \( t \):
- Remaining cost if sent today is \( bc \).
- Remaining cost if sent tomorrow is \( bx + c \).
- Tomorrow is preferable if \( (b - 1)c > bx \).
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General framework: quasi-hyperbolic discounting [Laibson 1997]

- Cost/reward $c$ realized $t$ units in future has present value $\beta \delta^t c$
- Special case: $\delta = 1$, $b = \beta^{-1}$, and agent is naive about bias.
- Can model procrastination, task abandonment [O’Donoghue-Rabin08], and benefits of choice reduction [Ariely and Wertenbroch 02, Kaur-Kremer-Mullainathan 10]
Cost ratio:

\[
\frac{\text{Cost incurred by present-biased agent}}{\text{Minimum cost achievable}}
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Across all stories in which present bias has an effect, what’s the worst cost ratio?

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\max_{S} \text{cost ratio}(S).
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Use graphs as basic structure to represent scenarios

[Kleinberg-Oren 2014]

- Agent plans to follow cheapest path from $s$ to $t$.
- From a given node, immediately outgoing edges have costs multiplied by $b > 1$. 
A Graph-Theoretic Framework

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Node $v_i =$ reaching day $i$ without sending the package.
Variation: agent only continues on path if cost ≤ reward at $t$.

- Can model abandonment: agent stops partway through a completed path.
- Can model benefits of choice reduction: deleting nodes can sometimes make graph become traversable.
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Paths with Rewards

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A More Elaborate Example

Three-week short course with two projects.

- Reward of 16 from finishing the course.
- Effort cost in a given week: 1 from doing no project, 4 from doing one, 9 from doing both.
- \( v_{ij} \) = the state in which \( i \) weeks of the course are done and the student has completed \( j \) projects.
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A Bad Example for the Cost Ratio

Cost ratio can be roughly $b^n$, and this is essentially tight.

Can we characterize the instances with exponential cost ratio?

- Goal, informally stated: Must any instance with large cost ratio contain Akerlof’s story as a sub-structure?
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Characterizing Bad Instances via Graph Minors
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The $k$-fan $\mathcal{F}_k$: the graph consisting of a $k$-node path, and one more node that all others link to.

**Theorem**

For every $\lambda > 1$ there exists $\varepsilon > 0$ such that if the cost ratio is $> \lambda^n$, then the underlying undirected graph of the instance contains an $\mathcal{F}_k$-minor for $k = \varepsilon n$. 

Choice reduction problem: Given $G$, not traversable by an agent, is there a subgraph of $G$ that is traversable?

- Our initial idea: if there is a traversable subgraph in $G$, then there is a traversable subgraph that is a path.
- But this is not the case.

Results:
- A characterization of the structure of minimal traversable subgraphs.
- NP-completeness [Feige 2014, Tang et al 2015]
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Sophisticated agents [O’Donoghue-Rabin 1999]

- Can successfully anticipate their behavior in the future.
- Plan in the present based on this awareness.

Example: It’s Thursday; a progress report must be written and submitted by Saturday at midnight.

- Cost to do it Thursday = 3.
- Cost to do it Friday = 5.
- Cost to do it Saturday = 9.

A struggle between three selves: one for each of Thurs, Fri, Sat.

- On Saturday: must be done for cost of 9.
- Your Friday self perceives the cost as $2 \cdot 5 = 10 > 9$. Makes the Saturday self do it.
- Your Thursday self perceives the cost as $2 \cdot 3 = 6$. But doesn't want to leave the decision to the Friday self (since $6 < 9$).
A graph-theoretic model of sophisticated planning
[Kleinberg-Oren-Raghavan 2016]

- There is a “self” for each node.
- Working backward in a topological ordering of the graph, determine what the self at node $v$ will do, given known behaviors at later nodes.
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Sophisticated agent can be $c$ times worse than optimal, for any $c \leq b$. 

Theorem [Kleinberg-Oren-Raghavan 2016]: In every instance $G$, a sophisticated agent incurs at most $b$ times the optimal cost. 

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Reasoning about long-range planning requires a model for decisions.

Graph-theoretic framework for present bias uncovers new questions and new phenomena.

Can study the interaction of multiple biases: present bias and sunk-cost bias [Kleinberg-Oren-Raghavan 2017].

Connecting these ideas back to incentive design.