**Introduction**

Our vision: sports analytics = branch of reinforcement learning.
- Fundamental question: which actions contribute to winning in what situation?
- Answer: learn an action-value function or Q-function.

**Motivation**

Advantages over previous action-based analytics (plus-minus, Corsi, Fenwick).
- Context-Awareness. Action values depend on context = state.
- Example: Goals are worth more with tied scores than with a 2-goal lead.
- Lookahead. Actions can have medium-term impact.
- Example: Penalties can lead to goals but not immediately.

**Related Work**

- Total Hockey Rating (THoR) [3] assigns a value to all ice hockey player actions. No context, fixed look-ahead window (20 sec).

**Data Set**

- 2.8M events, > 600K play sequences.

<table>
<thead>
<tr>
<th>GameId</th>
<th>Period</th>
<th>Sequence Number</th>
<th>Event Number</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>PERIOD START</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>faceoff(Home,Neutral)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>hit(Away,Neutral)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>takeaway(Home,Defensive)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>missed shot(Away,Offensive)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>shot(Away,Offensive)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>missed shot(Away,Neutral)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>9</td>
<td>goal(Home,Offensive)</td>
</tr>
</tbody>
</table>

**Markov Game Model**

A Markov Game Model [1] consists of 4 components:
- **State Space**, Transition Graph + Probabilities, Rewards
  - **Players** = Home, Away.
  - **State** = (Goal Differential, ManPower Differential, Period, Action History within play sequence)
  - Transition probabilities estimated from the number of observed occurrences.
- >1.3 M states with >0 occurrences.

**State Transition Examples**

<table>
<thead>
<tr>
<th>GameId</th>
<th>Period</th>
<th>Sequence Number</th>
<th>Event Number</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>PERIOD START</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>faceoff(Home,Neutral)</td>
</tr>
</tbody>
</table>

**Rewards/Costs**

- Score Goal/Incur Penalty.

**Value Iteration for Q-Learning**

Since states encode action histories, the expected value of states is equivalent to learning a Q-function \( V = Q \).

\[
Q_{i\mu}(s) = R(s) + \frac{1}{\text{Occ}(s)} \sum_{(s',a)} \left( \text{Occ}(s,a) \times Q_i(s') \right)
\]

**Applications of the Q-function**

- Knowledge Discovery. Cervone et al. [2]: “We assert that most questions that coaches, players, and fans have ...can be phrased and answered in terms of EPV [i.e., the Q-function].”
- Player ranking. Add up the total impact of a player’s actions.

**Conclusion**

- The Q-function is a powerful AI concept that captures much information about hockey dynamics (or other sports).
- Novel player ranking method based on reinforcement learning.
- The Q-impact of an action varies greatly with context, and medium-term ripple effects make a difference.
- Goal Impact scores correlate with points.