Multi-agent event recognition in structured scenarios: Appendix

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In this appendix we provide the formulas used for MLN inference. These formulas relate events only to the following properties related to the game: possession, last_touched_hoop, can_dribble, must_clear, and must_check. Other related properties, such as proximity relationships between players, ball, and scene objects (e.g., hoop, 3-point line), are used only for *observation axioms* and for hypothesized event interval generation. Our set of rules is not complete and some rules are imperfect, as described in the main text. Events that were not modeled include violations (e.g., traveling, fouls) as well as rare events in our videos such as blocked shots and airballs. Our framework is able to yield good results despite this.

Variables m, s, and e are moments (see paper), i is an interval, and p is a player. Also, $P1$ and $P2$, with capital letters, are constants representing the two players. As in Alchemy, the weight associated with a formula precedes it (we use weights .5, 1, 2, and 4 for all formulas except for the possession observation formula, whose weight is based on interval length), and hard formulas are terminated by a period. Formulas are universally quantified, and variables are *typed* so that *moment* variables are grounded only with *moment* constants, *interval* variables are grounded only with *interval* constants, etc.

Property constraint axioms

$\texttt{must\_check}(m) \Rightarrow \neg\texttt{must\_clear}(m) \wedge \neg\texttt{last\_touched\_hoop}(m).$

$\texttt{must\_clear}(m) \Rightarrow \neg\texttt{must\_check}(m) \wedge \neg\texttt{last\_touched\_hoop}(m).$

$\texttt{last\_touched\_hoop}(m) \Rightarrow \neg\texttt{must\_check}(m) \wedge \neg\texttt{must\_clear}(m).$

$\texttt{possession}(P1, m) \Leftrightarrow \neg\texttt{possession}(P2, m).$

Event definition axioms

4.0 $\texttt{rebound}(p, i) \wedge \texttt{same\_start}(i, s) \wedge \texttt{meets}(i, e) \Rightarrow$
$\texttt{last\_touched\_hoop}(s) \wedge \neg\texttt{last\_touched\_hoop}(e) \wedge \texttt{can\_dribble}(e) \wedge$
$(\texttt{possession}(p, s) \vee \texttt{must\_clear}(e)) \wedge \texttt{possession}(p, e)$

4.0 $\texttt{clear}(p, i) \wedge \texttt{same\_start}(i, s) \wedge \texttt{meets}(i, e) \Rightarrow$
$\texttt{possession}(p, s) \wedge \texttt{possession}(p, e) \wedge$
$\texttt{must\_clear}(s) \wedge \neg\texttt{must\_clear}(e)$

4.0 $\texttt{check}(p, i) \wedge \texttt{same\_start}(i, s) \wedge \texttt{meets}(i, e) \Rightarrow$
$\texttt{possession}(p, s) \wedge \texttt{possession}(p, e) \wedge$
$\texttt{must\_check}(s) \wedge \neg\texttt{must\_check}(e) \wedge \texttt{can\_dribble}(e)$

4.0 $\texttt{shot\_missed}(p, i) \wedge \texttt{same\_start}(i, s) \wedge \texttt{meets}(i, e) \Rightarrow$
$\texttt{possession}(p, s) \wedge \texttt{possession}(p, e) \wedge$
$\neg\texttt{must\_clear}(s) \wedge \neg\texttt{must\_check}(s) \wedge$
$\neg\texttt{last\_touched\_hoop}(s) \wedge \neg\texttt{can\_dribble}(s) \wedge \texttt{last\_touched\_hoop}(e)$

4.0 $\texttt{shot\_made}(p, i) \wedge \texttt{same\_start}(i, s) \wedge \texttt{meets}(i, e) \Rightarrow$
$\texttt{possession}(p, s) \wedge \texttt{possession}(p, e) \wedge$
$\neg\texttt{must\_clear}(s) \wedge \neg\texttt{must\_check}(s) \wedge$
$\neg\texttt{last\_touched\_hoop}(s) \wedge \neg\texttt{can\_dribble}(s) \wedge \texttt{must\_check}(e)$

4.0 $\texttt{out\_of\_bounds}(p, i) \wedge \texttt{same\_start}(i, s) \wedge \texttt{meets}(i, e) \Rightarrow$
$\neg\texttt{possession}(p, e) \wedge \neg\texttt{must\_check}(s) \wedge$
$\texttt{must\_check}(e) \wedge \neg\texttt{can\_dribble}(s)$

4.0 $\texttt{steal}(p, i) \wedge \texttt{same\_start}(i, s) \wedge \texttt{meets}(i, e) \Rightarrow$
$\neg\texttt{possession}(p, s) \wedge \texttt{possession}(p, e) \wedge$
$\neg\texttt{last\_touched\_hoop}(s) \wedge \neg\texttt{must\_check}(s) \wedge$
$\neg\texttt{must\_check}(e) \wedge \texttt{can\_dribble}(e)$

4.0 $\texttt{dribble\_series}(p, i) \wedge \texttt{same\_start}(i, s) \wedge \texttt{meets}(i, e) \Rightarrow$
$\texttt{possession}(p, s) \wedge \texttt{possession}(p, e) \wedge$
$\texttt{can\_dribble}(s) \wedge \neg\texttt{can\_dribble}(e)$

Event mutual exclusion axioms

$\texttt{intersects}(i_1, i_2) \wedge \texttt{shot\_made}(p_1, i_1) \wedge (\neg(p_1 = p_2) \vee \neg(i_1 = i_2)) \Rightarrow \neg\texttt{shot\_made}(p_2, i_2).$

$\texttt{intersects}(i_1, i_2) \wedge \texttt{shot\_missed}(p_1, i_1) \wedge (\neg(p_1 = p_2) \vee \neg(i_1 = i_2)) \Rightarrow \neg\texttt{shot\_missed}(p_2, i_2).$

$\texttt{intersects}(i_1, i_2) \wedge \texttt{shot\_made}(p_1, i_1) \Rightarrow \neg\texttt{shot\_missed}(p_2, i_2).$

$\texttt{intersects}(i_1, i_2) \wedge \texttt{shot\_missed}(p_1, i_1) \Rightarrow \neg\texttt{shot\_made}(p_2, i_2).$

$\texttt{intersects}(i_1, i_2) \wedge \texttt{check}(p_1, i_1) \wedge (\neg(p_1 = p_2) \vee \neg(i_1 = i_2)) \Rightarrow \neg\texttt{check}(p_2, i_2).$

$\texttt{intersects}(i_1, i_2) \wedge \texttt{rebound}(p_1, i_1) \wedge (\neg(p_1 = p_2) \vee \neg(i_1 = i_2)) \Rightarrow \neg\texttt{rebound}(p_2, i_2).$

$\texttt{intersects}(i_1, i_2) \wedge \texttt{clear}(p_1, i_1) \wedge (\neg(p_1 = p_2) \vee \neg(i_1 = i_2)) \Rightarrow \neg\texttt{clear}(p_2, i_2).$

$\texttt{intersects}(i_1, i_2) \wedge \texttt{out\_of\_bounds}(p_1, i_1) \wedge (\neg(p_1 = p_2) \vee \neg(i_1 = i_2)) \Rightarrow \neg\texttt{out\_of\_bounds}(p_2, i_2).$

$\texttt{intersects}(i_1, i_2) \wedge \texttt{steal}(p_1, i_1) \wedge (\neg(p_1 = p_2) \vee \neg(i_1 = i_2)) \Rightarrow \neg\texttt{steal}(p_2, i_2).$

$\texttt{intersects}(i_1, i_2) \wedge \texttt{dribble\_series}(p_1, i_1) \wedge (\neg(p_1 = p_2) \vee \neg(i_1 = i_2)) \Rightarrow \neg\texttt{dribble\_series}(p_2, i_2).$

Event explanation closure axioms

4.0 $\texttt{meets}((s, e) \wedge \texttt{possession}(p_1, s) \wedge \texttt{possession}(p_2, e) \wedge \neg(p_1 = p_2) \Rightarrow$
$\exists i_1(\texttt{meets}(i_1, e) \wedge \texttt{rebound}(p_2, i_1)) \vee$
$\exists i_2(\texttt{same\_start}(i_2, e) \wedge \texttt{out\_of\_bounds}(p_1, i_2)) \vee$
$\exists i_3(\texttt{meets}(i_3, e) \wedge \texttt{steal}(p_2, i_3)$

4.0 $\texttt{meets}(s,e) \wedge \texttt{must\_clear}(s) \wedge \neg\texttt{must\_clear}(e) \Rightarrow$
$\exists p, i_1(\texttt{meets}(i_1,e) \wedge \texttt{clear}(p,i_1)) \vee$
$\exists p, i_2(\texttt{same\_start}(i_2,e) \wedge \texttt{out\_of\_bounds}(p,i_2))$

4.0 $\texttt{meets}(s,e) \wedge \neg\texttt{must\_clear}(s) \wedge \texttt{must\_clear}(e) \Rightarrow$
$\exists p, i(\texttt{meets}(i,e) \wedge \texttt{rebound}(p,i) \wedge \neg\texttt{possession}(p,s))$

4.0 $\texttt{meets}(s,e) \wedge \texttt{can\_dribble}(s) \wedge \neg\texttt{can\_dribble}(e) \Rightarrow$
$\exists p, i_1(\texttt{meets}(i_1,e) \wedge \texttt{dribble\_series}(p,i_1)) \vee$
$\exists p, i_2(\texttt{same\_start}(i_2,e) \wedge \texttt{shot\_made}(p,i_2)) \vee$
$\exists p, i_3(\texttt{same\_start}(i_3,e) \wedge \texttt{shot\_missed}(p,i_3)) \vee$
$\exists p, i_4(\texttt{same\_start}(i_4,e) \wedge \texttt{out\_of\_bounds}(p,i_4))$

4.0 $\texttt{meets}(s,e) \wedge \neg\texttt{can\_dribble}(s) \wedge \texttt{can\_dribble}(e) \Rightarrow$
$\exists p, i_1(\texttt{meets}(i_1,e) \wedge \texttt{rebound}(p,i_1)) \vee$
$\exists p, i_2(\texttt{meets}(i_2,e) \wedge \texttt{check}(p,i_2)) \vee$
$\exists p, i_3(\texttt{meets}(i_3,e) \wedge \texttt{steal}(p,i_3))$

4.0 $\texttt{meets}(s,e) \wedge \neg\texttt{last\_touched\_hoop}(s) \wedge \texttt{last\_touched\_hoop}(e) \Rightarrow$
$\exists p, i(\texttt{meets}(i,e) \wedge \texttt{shot\_missed}(p,i))$

4.0 $\texttt{meets}(s,e) \wedge \texttt{last\_touched\_hoop}(s) \wedge \neg\texttt{last\_touched\_hoop}(e) \Rightarrow$
$\exists p, i_1(\texttt{meets}(i_1,e) \wedge \texttt{rebound}(p,i_1)) \vee$
$\exists p, i_2(\texttt{same\_start}(i_2,e) \wedge \texttt{out\_of\_bounds}(p,i_2))$

4.0 $\texttt{meets}(s,e) \wedge \neg\texttt{must\_check}(s) \wedge \texttt{must\_check}(e) \Rightarrow$
$\exists p, i_1(\texttt{meets}(i_1,e) \wedge \texttt{shot\_made}(p,i_1)) \vee$
$\exists p, i_2(\texttt{same\_start}(i_2,e) \wedge \texttt{out\_of\_bounds}(p_2,i_2))$

4.0 $\texttt{meets}(s,e) \wedge \texttt{must\_check}(s) \wedge \neg\texttt{must\_check}(e) \Rightarrow$
$\exists p, i(\texttt{meets}(i,e) \wedge \texttt{check}(p,i))$

Observation axioms

2.0 $\texttt{obs\_shot}(i) \Rightarrow \exists p(\texttt{shot\_missed}(p,i) \vee \texttt{shot\_made}(p,i))$

0.5 $\texttt{obs\_shot\_missed}(p,i) \Rightarrow \texttt{shot\_missed}(p,i)$

0.5 $\texttt{obs\_shot\_made}(p,i) \Rightarrow \texttt{shot\_made}(p,i)$

2.0 $\texttt{obs\_check}(p,i) \Rightarrow \texttt{check}(p,i)$

0.5 $\texttt{obs\_out\_of\_bounds}(p,i) \Rightarrow \texttt{out\_of\_bounds}(p,i)$

0.25 $\texttt{obs\_dribble\_series}(p,i) \Rightarrow \texttt{dribble\_series}(p,i)$

$10^{-5}F_{p,m}$ $\texttt{obs\_possession}(p,m) \Rightarrow \texttt{possession}(p,m)$

Here, $F_{p,m}$ is the total number of frames f in moment m for which $\texttt{possession}(p,f)$ is implied by $\texttt{obs\_nearest\_ball}(p,f) \wedge \neg\texttt{obs\_nearest\_hoop}(p,f) \Rightarrow \texttt{possession}(p,f)$.