

# Spatio-temporal challenges in analyzing soccer data

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# Tracking Data in Bundesliga

- x/y coordinates of players and ball recorded at 25fps
- some flags, e.g., ball possession indicator
- accompanied by manually annotated event data
- tracking and event data sometimes come from different providers and need to be sync'ed before they can be processed together



# Data at a glimpse...

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6     Height="182" Weight="75" Clubid="DFL-CLU-000N8Y" ClubName="Deutschland Nationalmannschaft" ValidFrom="2019-06-06T12:45:43.677+02:00"/>
7     <Object Objectid="DFL-Obj-002B30" DIProviderid="32" Type="assistantHeadcoach" Name="Andreas Köpcke" FirstName="Andreas" LastName="Köpcke" BirthDate="12.03.1962"
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9     Height="162" Weight="80" Clubid="DFL-CLU-000N8Y" ClubName="Deutschland Nationalmannschaft" ValidFrom="2019-06-06T12:45:43.677+02:00"/>
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5     BirthPlace="Stuttgart" CountryOfBirthGerman="Deutschland" CountryOfBirthEnglish="Germany" CountryOfBirthSpanish="Alemania" NationalityGerman="Deutsch" NationalityEnglish="German"
6     NationalitySpanish="alemán" AdditionalNationalityOneGerman="Ivorisch" AdditionalNationalityOneEnglish="Ivorian" AdditionalNationalityOneSpanish="marfileño" Height="175" Weight="75"
7     ShirtNumber="20" PrimaryPool="true" PlayingPositionGerman="Mittelfeld" PlayingPositionEnglish="midfield" PlayingPositionSpanish="medio campo" ClubId="DFL-CLU-000N8Y" ClubName="Deutschland
8     Nationalmannschaft" ValidFrom="2019-06-11T16:01:48.220+02:00"/>
9     <Object Objectid="DFL-Obj-0001UP" DIProviderId="48918" Type="player" Name="Jonathan Glig Tah" FirstName="Jonathan Glig" LastName="Tah" Alias="Jonathan Tah" BirthDate="11.02.1993"
10    BirthPlace="Hamburg" CountryOfBirthGerman="Deutschland" CountryOfBirthEnglish="Germany" CountryOfBirthSpanish="Alemania" NationalityGerman="Deutsch" NationalityEnglish="German"
11    NationalitySpanish="alemán" AdditionalNationalityOneGerman="Ivorisch" AdditionalNationalityOneEnglish="Ivorian" AdditionalNationalityOneSpanish="marfileño" Height="195" Weight="87"
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13    Nationalmannschaft" ValidFrom="2019-06-11T16:01:48.220+02:00"/>
14    <Object Objectid="DFL-Obj-00258K" DIProviderId="50274" Type="player" Name="Thilo Kehrer" FirstName="Thilo" LastName="Kehrer" BirthDate="21.09.1996" BirthPlace="Tübingen"
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17    ClubName="Deutschland Nationalmannschaft" ValidFrom="2019-06-05T12:45:43.577+02:00"/>
18    <Object Objectid="DFL-Obj-0000LT" DIProviderId="33669" Type="player" Name="Sven Ulreich" FirstName="Sven" LastName="Ulreich" BirthDate="03.08.1988" BirthPlace="Schorndorf"
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21    ClubName="Deutschland Nationalmannschaft" ValidFrom="2019-06-05T12:45:43.577+02:00"/>
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26    <Object Objectid="DFL-Obj-00012X" DIProviderId="47041" Type="player" Name="Jonas Hector" FirstName="Jonas" LastName="Hector" BirthDate="27.05.1990" BirthPlace="Saarbrücken"
27    CountryOfBirthGerman="Deutschland" CountryOfBirthEnglish="Germany" CountryOfBirthSpanish="Alemania" NationalityGerman="Deutsch" NationalityEnglish="German" NationalitySpanish="alemán"
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30    <Object Objectid="DFL-Obj-0000C6" DIProviderId="36772" Type="player" Name="Marco Reus" FirstName="Marco" LastName="Reus" BirthDate="31.05.1989" BirthPlace="Dortmund"
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33    ClubName="Deutschland Nationalmannschaft" ValidFrom="2019-06-05T12:45:43.577+02:00"/>
34    <Object Objectid="DFL-Obj-0000QJ" DIProviderId="37636" Type="player" Name="Ilkay Gündogan" FirstName="Ilkay" LastName="Gündogan" BirthDate="24.10.1990" BirthPlace="Gelsenkirchen"
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36    Height="180" Weight="79" ShirtNumber="21" PrimaryPool="true" PlayingPositionGerman="Mittelfeld" PlayingPositionEnglish="midfield" PlayingPositionSpanish="medio campo" ClubId="DFL-CLU-000N8Y"
37    ClubName="Deutschland Nationalmannschaft" ValidFrom="2019-06-05T12:45:43.577+02:00"/>
38    <Object Objectid="DFL-Obj-0000HC" DIProviderId="37876" Type="player" Name="Kevin Trapp" FirstName="Kevin" LastName="Trapp" BirthDate="08.07.1990" BirthPlace="Merzig"
39    CountryOfBirthGerman="Deutschland" CountryOfBirthEnglish="Germany" CountryOfBirthSpanish="Alemania" NationalityGerman="Deutsch" NationalityEnglish="German" NationalitySpanish="alemán"
40    Height="169" Weight="86" ShirtNumber="12" PrimaryPool="true" PlayingPositionGerman="Torwar" PlayingPositionEnglish="goalkeeper" PlayingPositionSpanish="portero" ClubId="DFL-CLU-000N8Y"
41    ClubName="Deutschland Nationalmannschaft" ValidFrom="2019-06-05T12:45:43.577+02:00"/>
42    <Object Objectid="DFL-Obj-0000SE" DIProviderId="43073" Type="player" Name="Nico Schulz" FirstName="Nico" LastName="Schulz" BirthDate="01.04.1993" BirthPlace="Berlin"
43    CountryOfBirthGerman="Deutschland" CountryOfBirthEnglish="Germany" CountryOfBirthSpanish="Alemania" NationalityGerman="Deutsch" NationalityEnglish="German" NationalitySpanish="alemán"
44    Height="180" Weight="82" ShirtNumber="14" PrimaryPool="true" PlayingPositionGerman="Verteidigung" PlayingPositionEnglish="defense" PlayingPositionSpanish="defensa" ClubId="DFL-CLU-000N8Y"
45    ClubName="Deutschland Nationalmannschaft" ValidFrom="2019-06-05T12:45:43.577+02:00"/>
46    <Object Objectid="DFL-Obj-0001F4" DIProviderId="44542" Type="player" Name="Marcel Halstenberg" FirstName="Marcel" LastName="Halstenberg" BirthDate="27.09.1991" BirthPlace="Laatzen"
47    CountryOfBirthGerman="Deutschland" CountryOfBirthEnglish="Germany" CountryOfBirthSpanish="Alemania" NationalityGerman="Deutsch" NationalityEnglish="German" NationalitySpanish="alemán"
48    Height="187" Weight="82" ShirtNumber="16" PrimaryPool="true" PlayingPositionGerman="Verteidigung" PlayingPositionEnglish="defense" PlayingPositionSpanish="defensa" ClubId="DFL-CLU-000N8Y"
49    ClubName="Deutschland Nationalmannschaft" ValidFrom="2019-06-05T12:45:43.577+02:00"/>
50    <Object Objectid="DFL-Obj-0000Z3" DIProviderId="46898" Type="player" Name="Matthias Lukas Ginter" FirstName="Matthias Lukas" LastName="Ginter" Alias="Matthias Ginter"
51    BirthDate="19.01.1994" BirthPlace="Freiburg" CountryOfBirthGerman="Deutschland" CountryOfBirthEnglish="Germany" CountryOfBirthSpanish="Alemania" NationalityGerman="Deutsch"
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5 SeasonId="DFL-SEA-0001K3" MatchDay="1" PlannedKickoffTime="2019-06-11T20:45:00.000+02:00" KickoffTime="2019-06-11T20:47:02.010+02:00" MatchId="DFL-MAT-003BEU" DIPProviderId="173185"
6 MatchTitle="Deutschland Nationalmannschaft:Estland Nationalmannschaft" HomeTeamName="Deutschland Nationalmannschaft" HomeTeamId="DFL-CLU-000N8Y" GuestTeamName="Estland
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8 <Environment Country="Deutschland" StadiumId="DFL-STA-00000E" StadiumName="OPEL ARENA" StadiumAddress="Eugen-Salomon-Straße 1, 55128 Mainz" Roof="open" Floodlight="off"
9 PitchErosion="none" NumberOfSpectators="0" StadiumCapacity="33305" Precipitation="none" SoldOut="false" PitchX="105.0" PitchY="63.0"/>
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16 TeamLeader="false"/>
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18 TeamLeader="false"/>
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21 <Player PersonId="DFL-OBJ-0002AU" ShirtNumber="19" FirstName="Leroy" LastName="Sane" Shortname="L. Sane" Starting="true" PlayingPosition="RA" TeamLeader="false"/>
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24 TeamLeader="false"/>
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48 <Player PersonId="DFL-OBJ-002FZQ" ShirtNumber="3" FirstName="Artur" LastName="Pikk" Shortname="A. Pikk" Starting="true" PlayingPosition="LV" TeamLeader="false"/>
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53 <Player PersonId="DFL-OBJ-002G0B" ShirtNumber="7" FirstName="Sander" LastName="Pur" Shortname="S. Pur" Starting="true" PlayingPosition="LM" TeamLeader="false"/>
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55 </Team>
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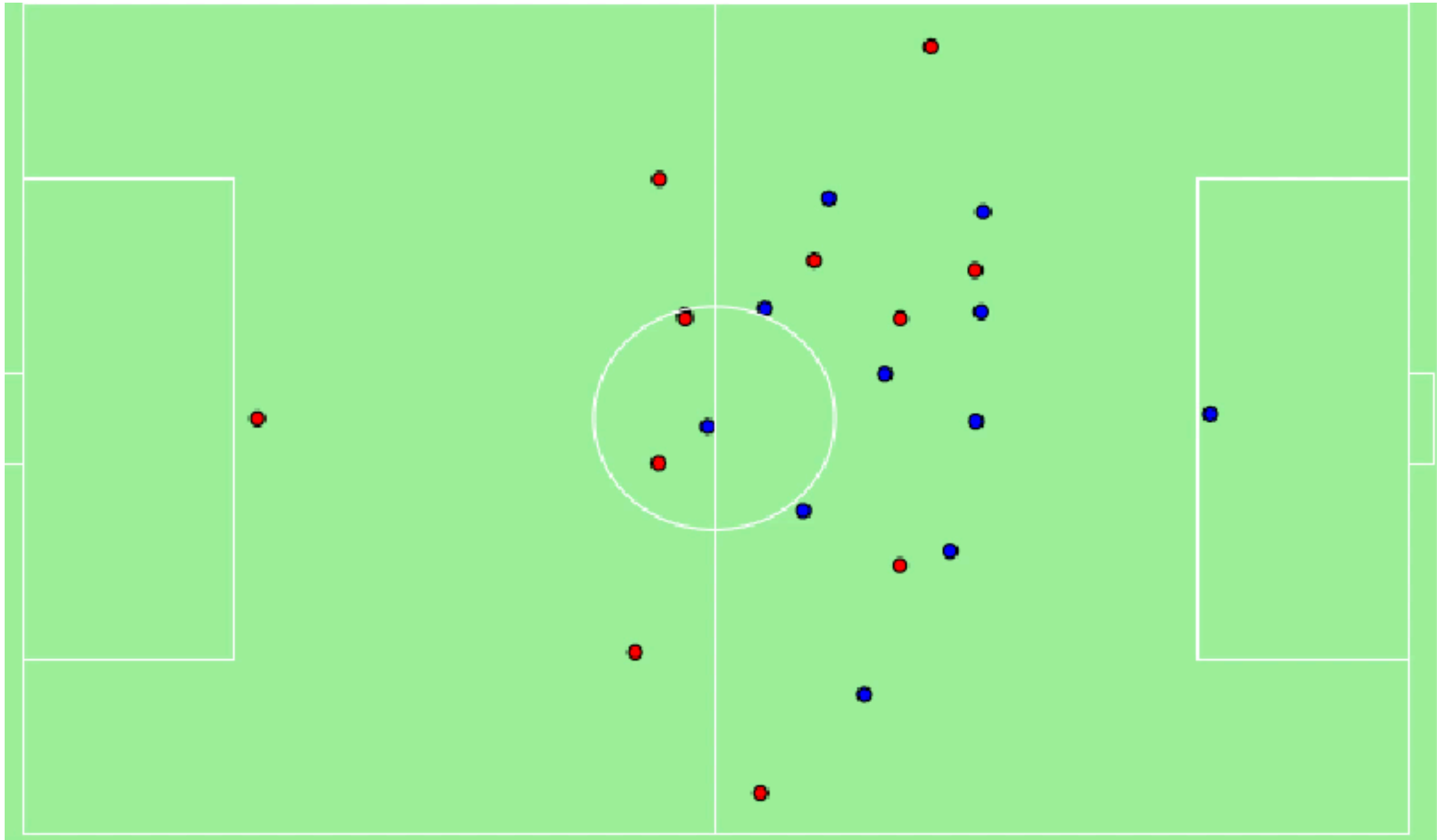
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```



```
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37 </Play>
```

# After some preprocessing...



# (Very) General Challenges

- Often, answering complex questions requires:
  - A computational model of what is possible
  - A computational representation of what happened
  - A computational understanding of alternative options of every player in any situation
  - A computational way to compute optimal actions
  - A computational value of how good observed actions are wrt to the optimal action

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- A computational understanding of alternative options of every player in any situation

- A computational way to compute optimal actions

- A computational value of how good observed actions are wrt to the optimal action

1st part

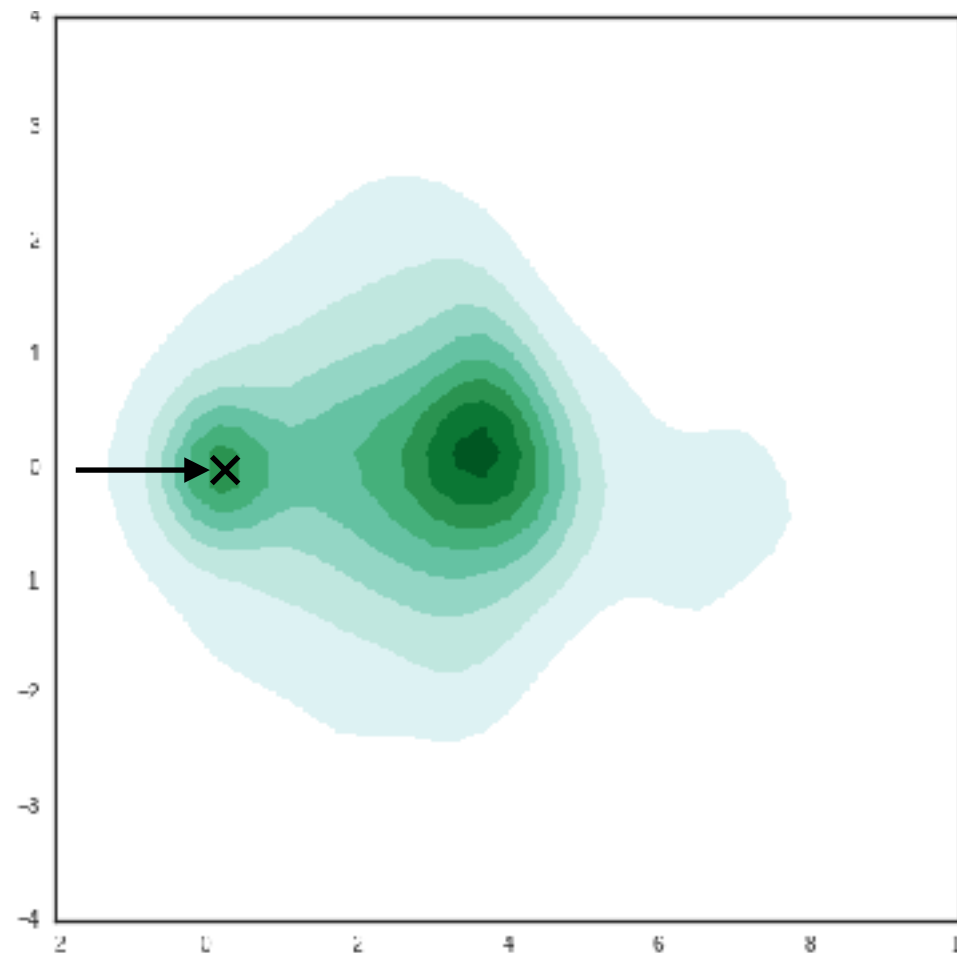
2nd part



# Movement Models

# Motion/Movement Models

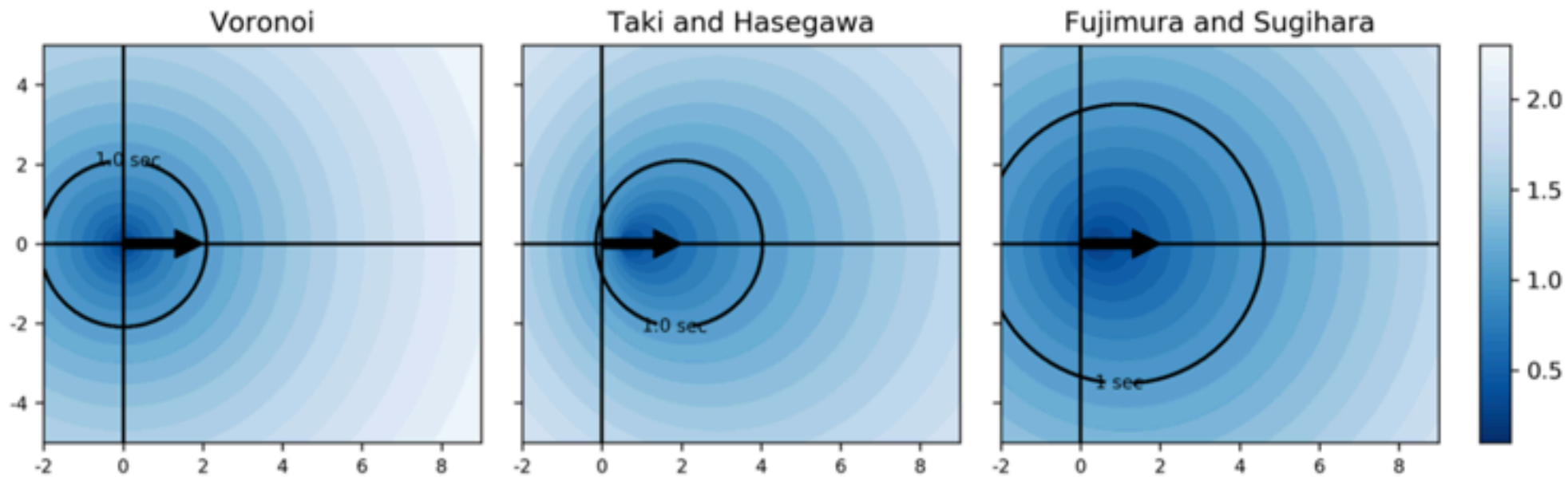
- A model that describes possible future movements in a time interval  $T$  of a player who is currently moving with velocity  $V$



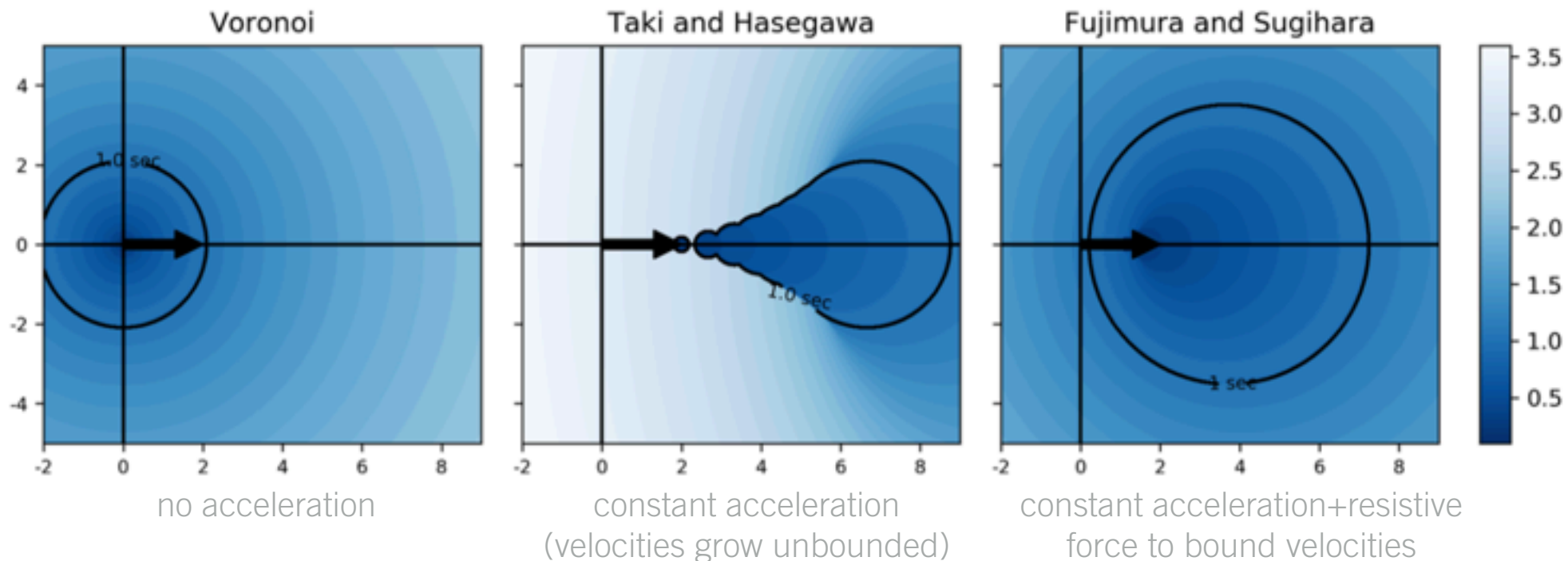
× initial position  
➔ direction of movement

# Traditional Movement Models

player running  
at 7km/h



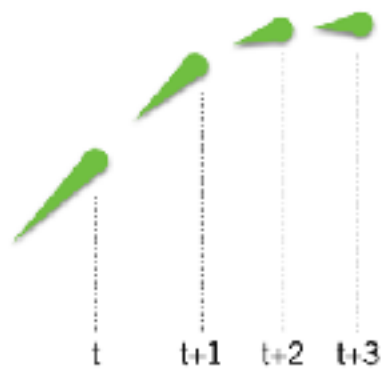
player running  
at 24km/h



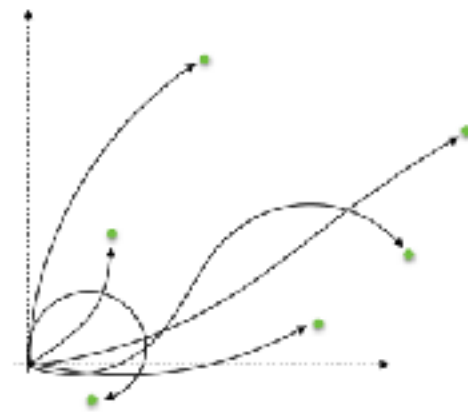
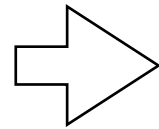


# A Frequentist Approach

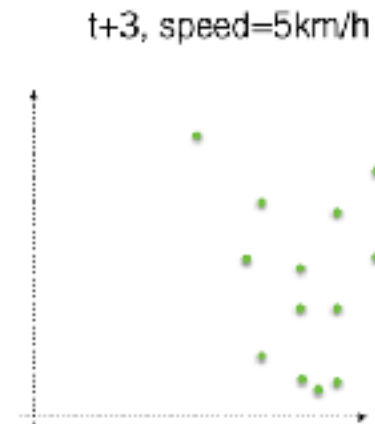
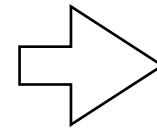
Brefeld, Lasek & Mair, MLJ (2019)



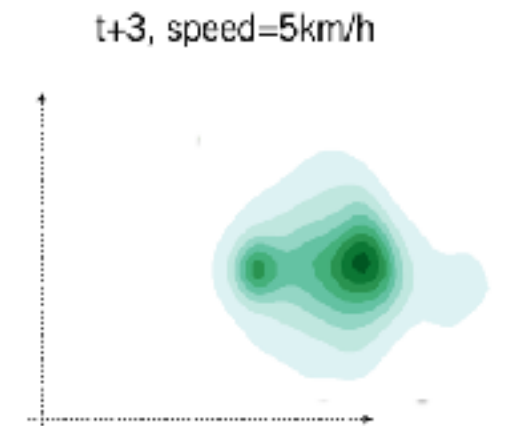
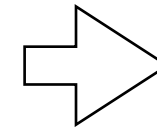
raw trajectories



rotate and map endpoints into new coordinate system



collect points wrt time window and speed

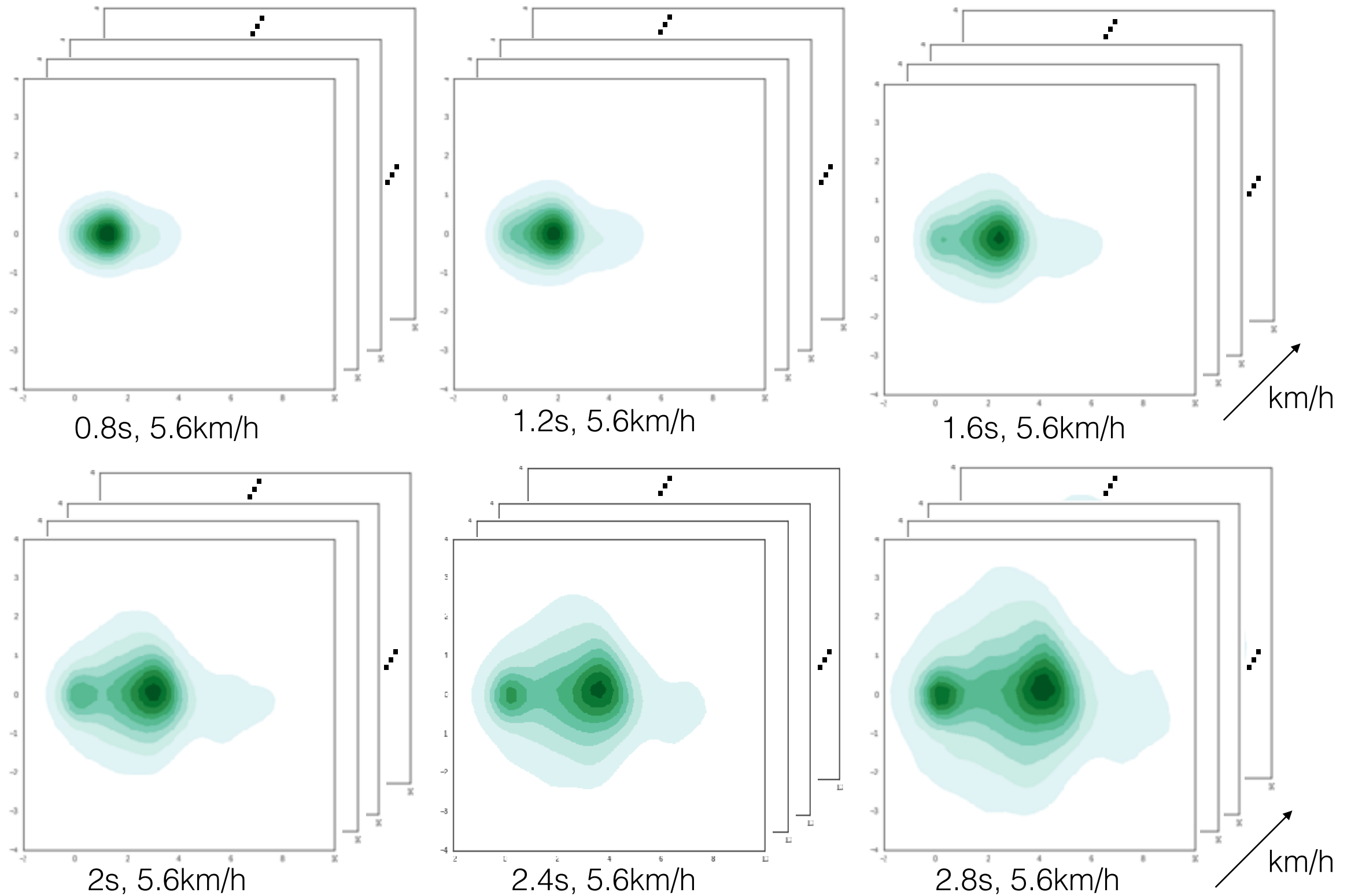


density estimation

- Frequency statistics of observations from historic games
- Straight forward and easy to implement

# Data-driven Movement Models

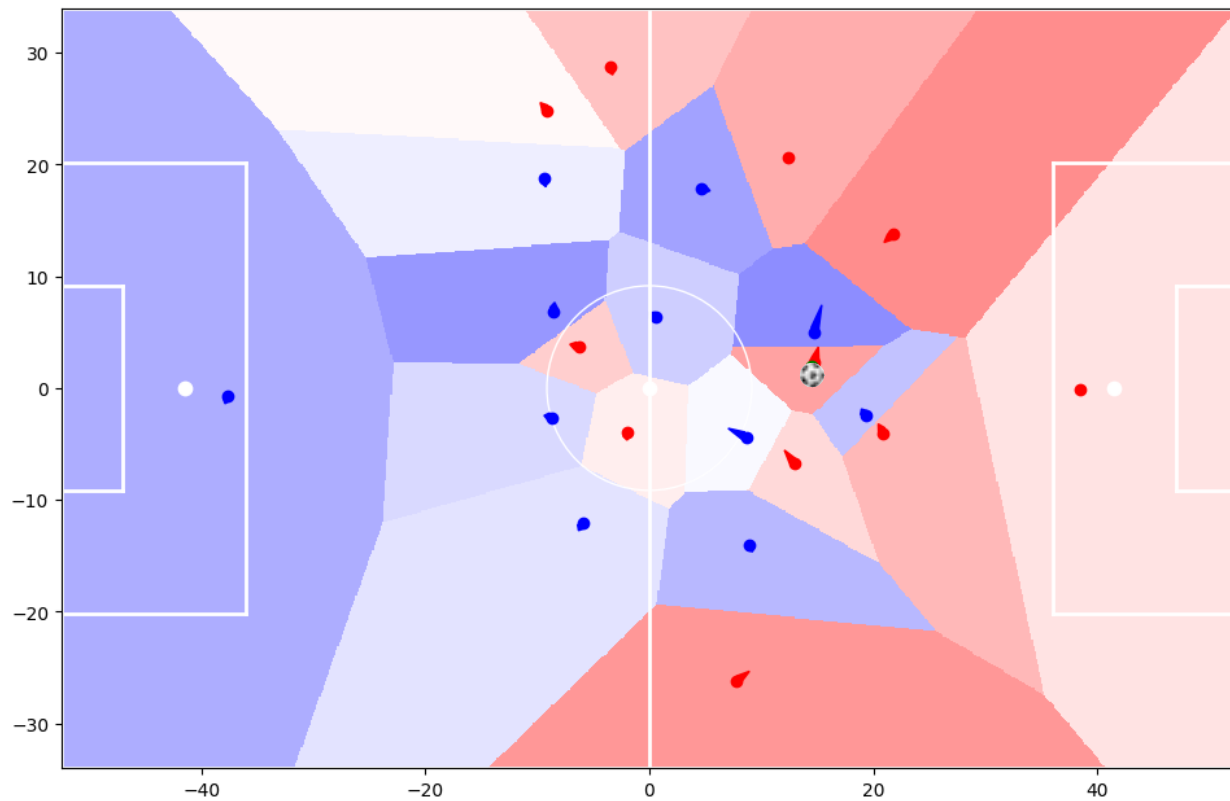
Brefeld, Lasek & Mair, MLJ (2019)



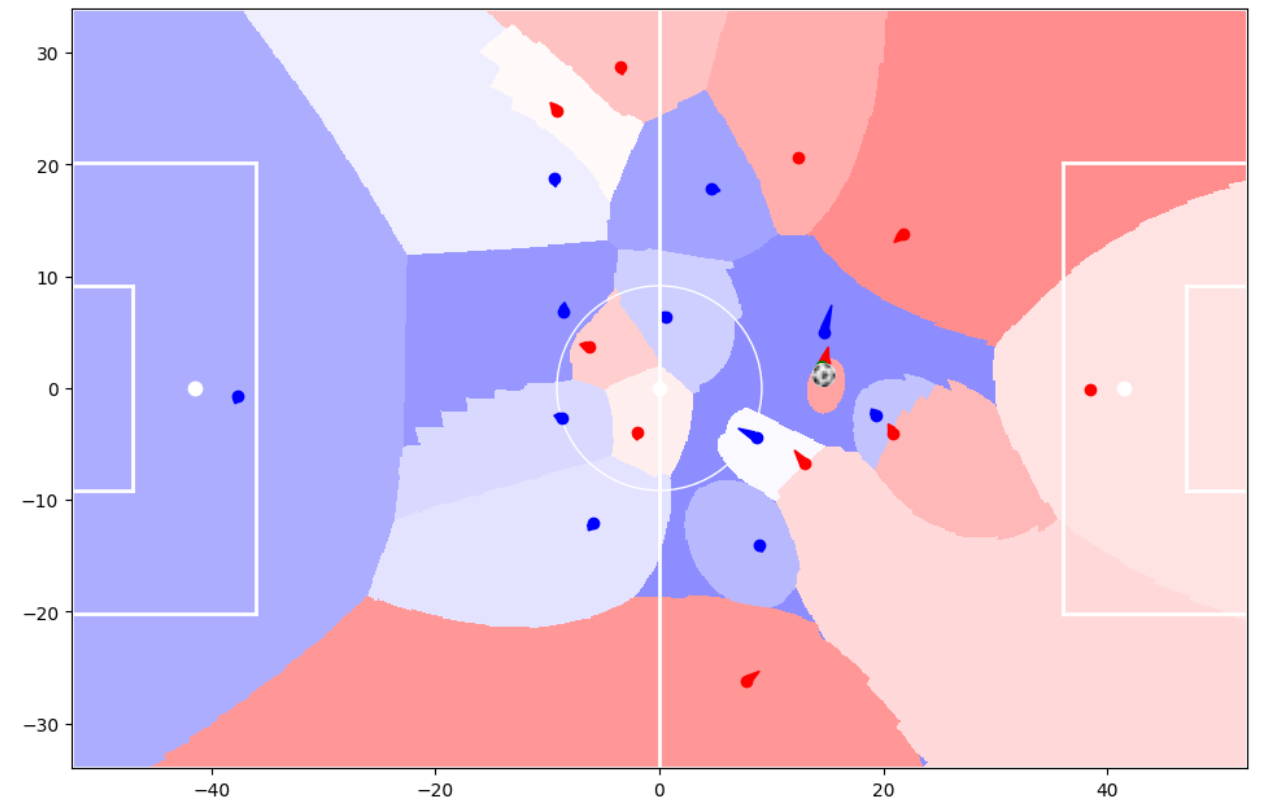
# Comparison

Brefeld, Lasek & Mair, MLJ (2019)

## Voronoi



## data-driven



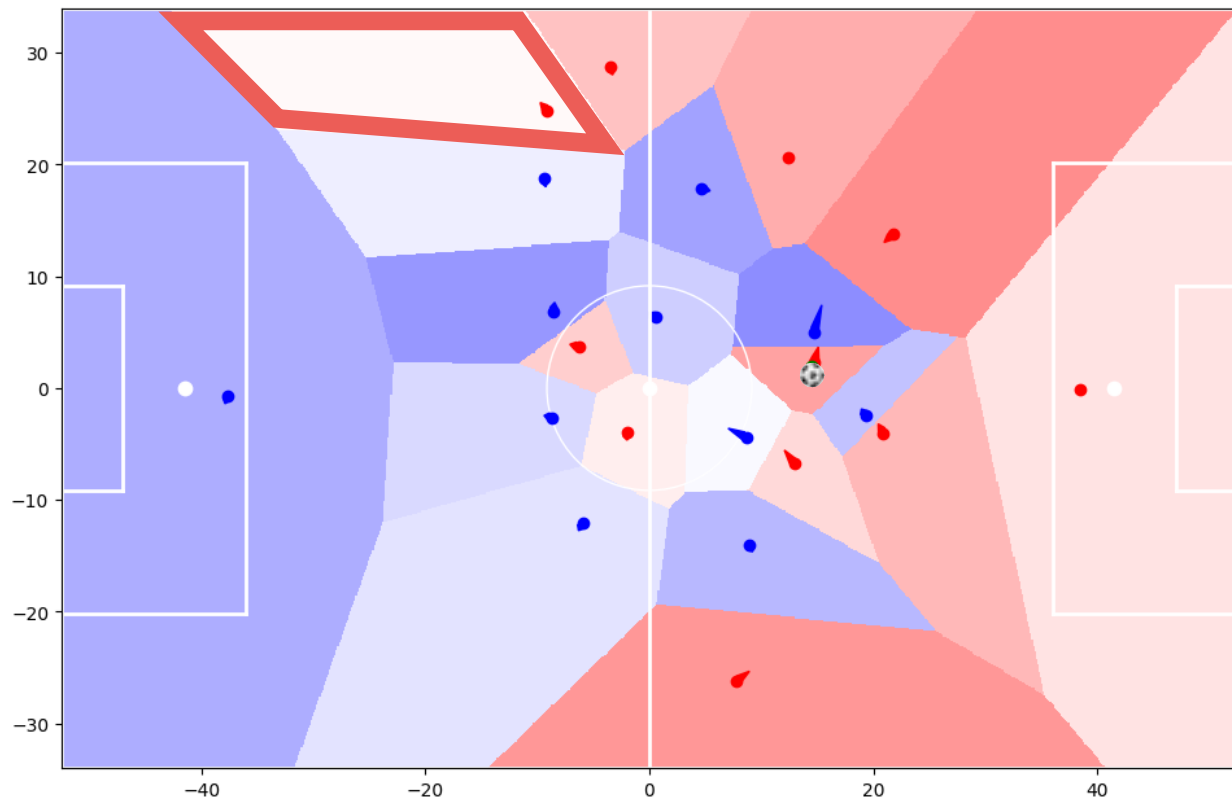
- Many differences, some critical for game analyses!
- Data-driven movement models offer realistic interpretations



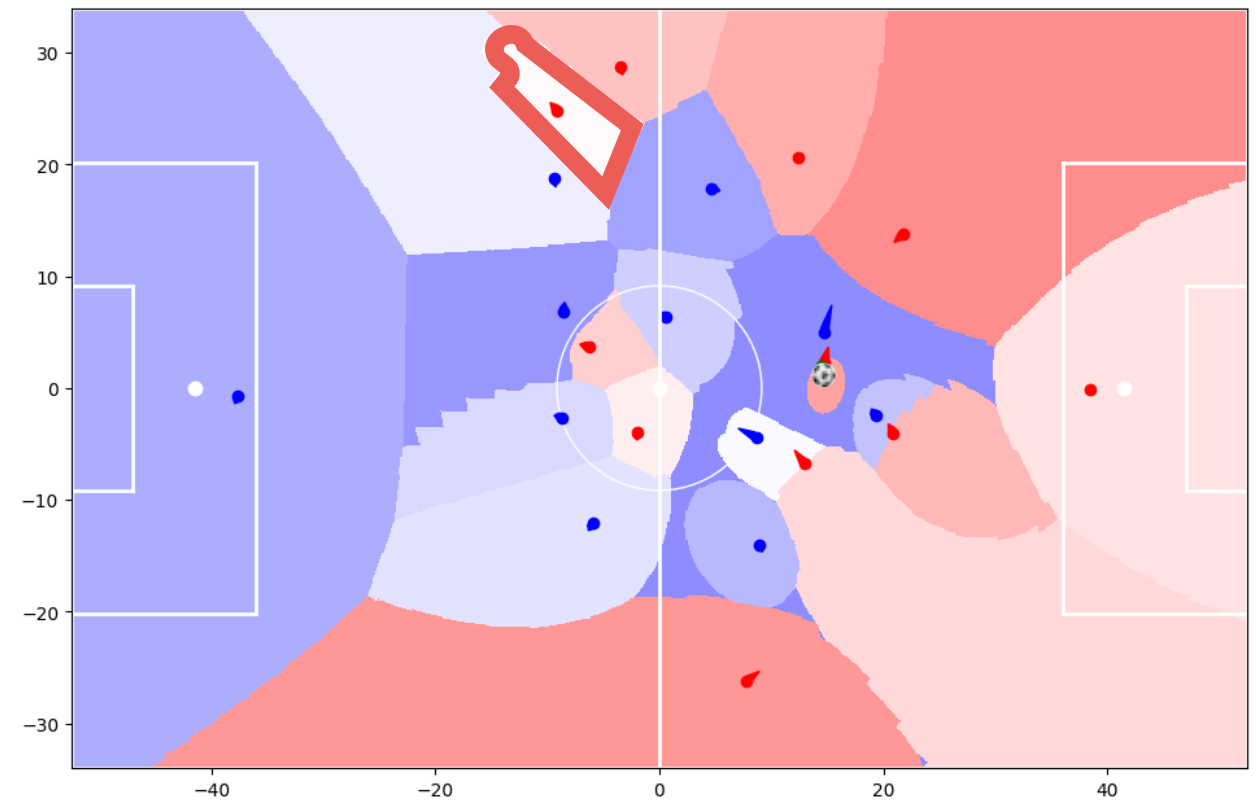
# Comparison

Brefeld, Lasek & Mair, MLJ (2019)

## Voronoi



## data-driven

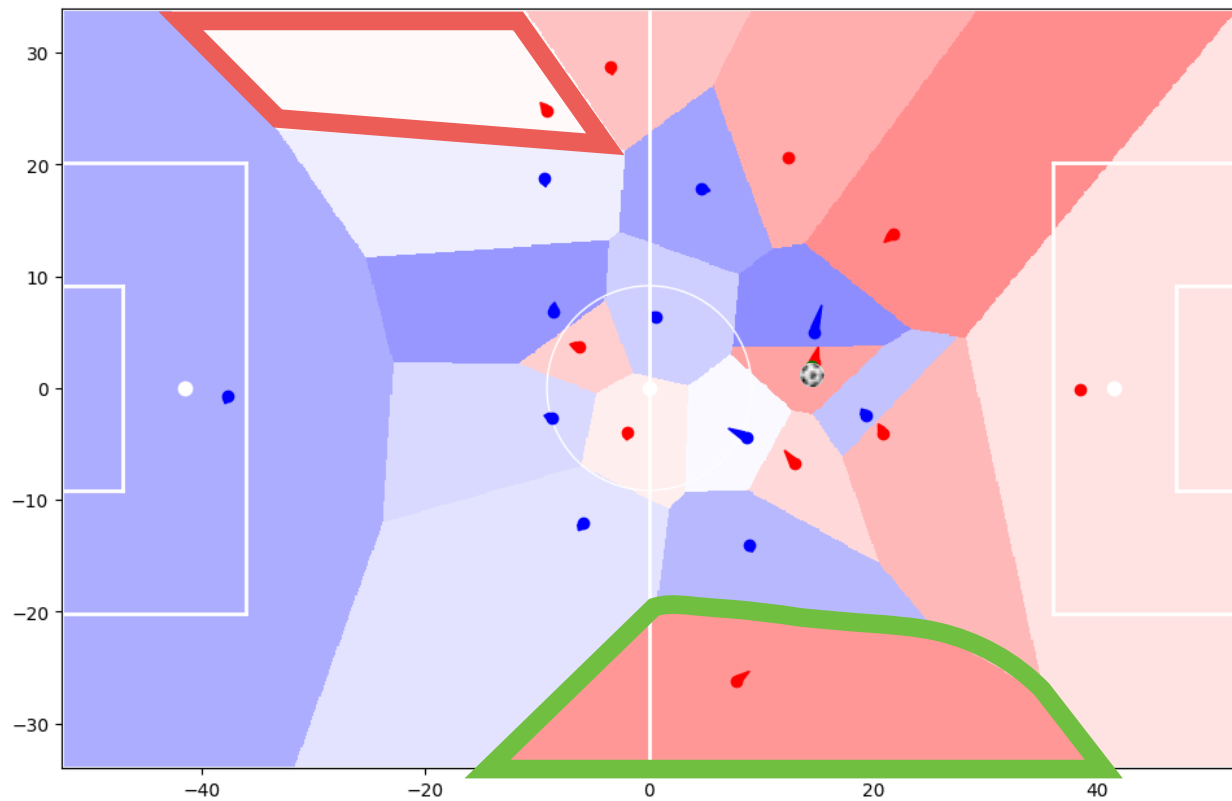


- Many differences, some critical for game analyses!
- Data-driven movement models offer realistic interpretations

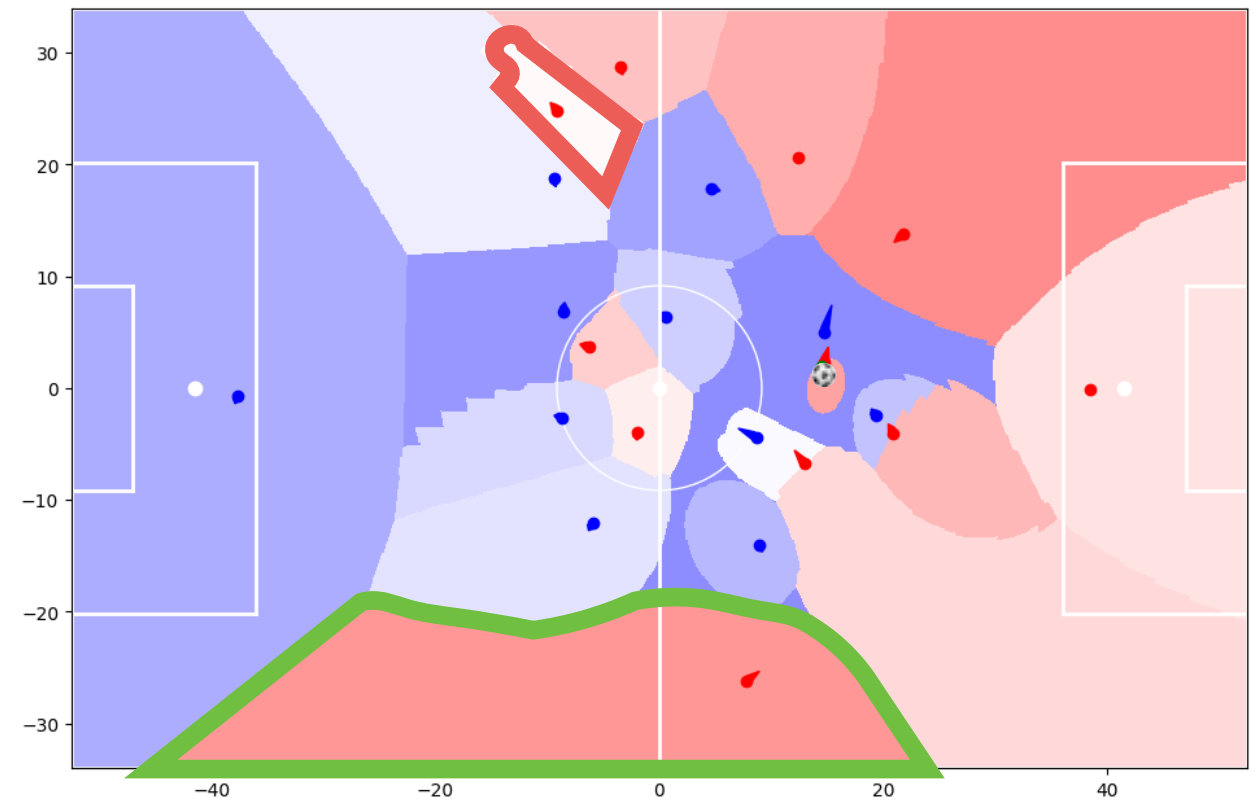
# Comparison

Brefeld, Lasek & Mair, MLJ (2019)

## Voronoi



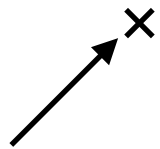
## data-driven



- Many differences, some critical for game analyses!
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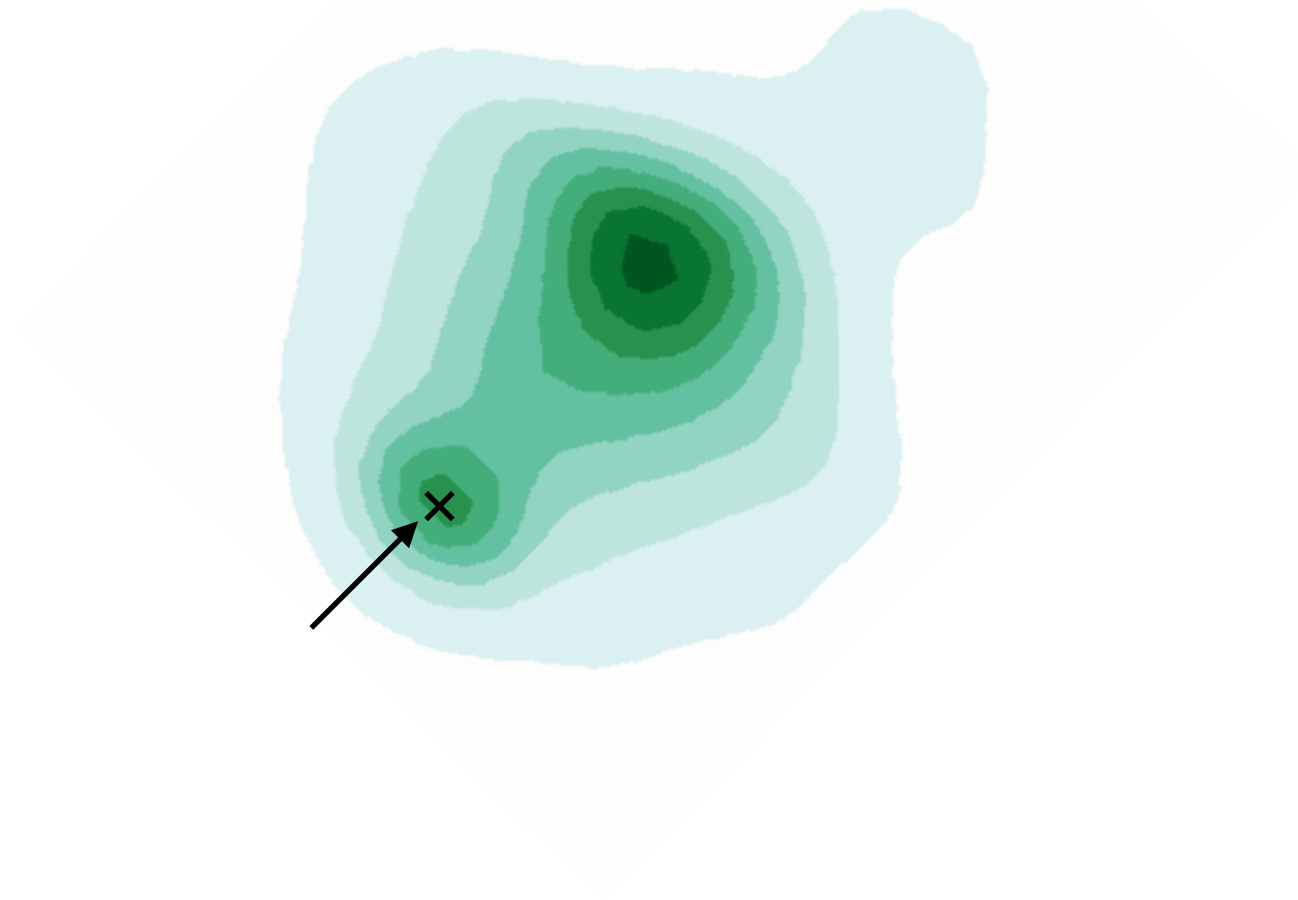
# Limitations

- Movement model ignores context of players:



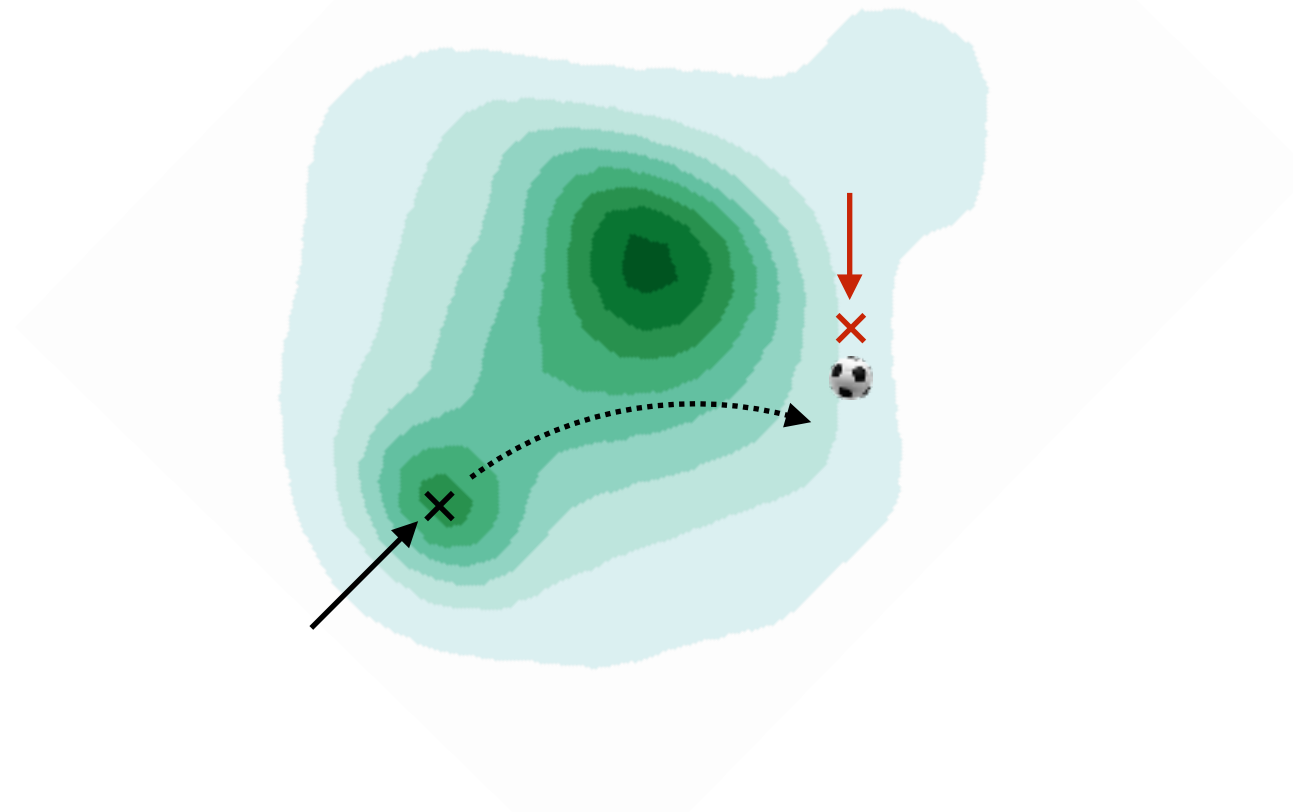
# Limitations

- Movement model ignores context of players:



# Limitations

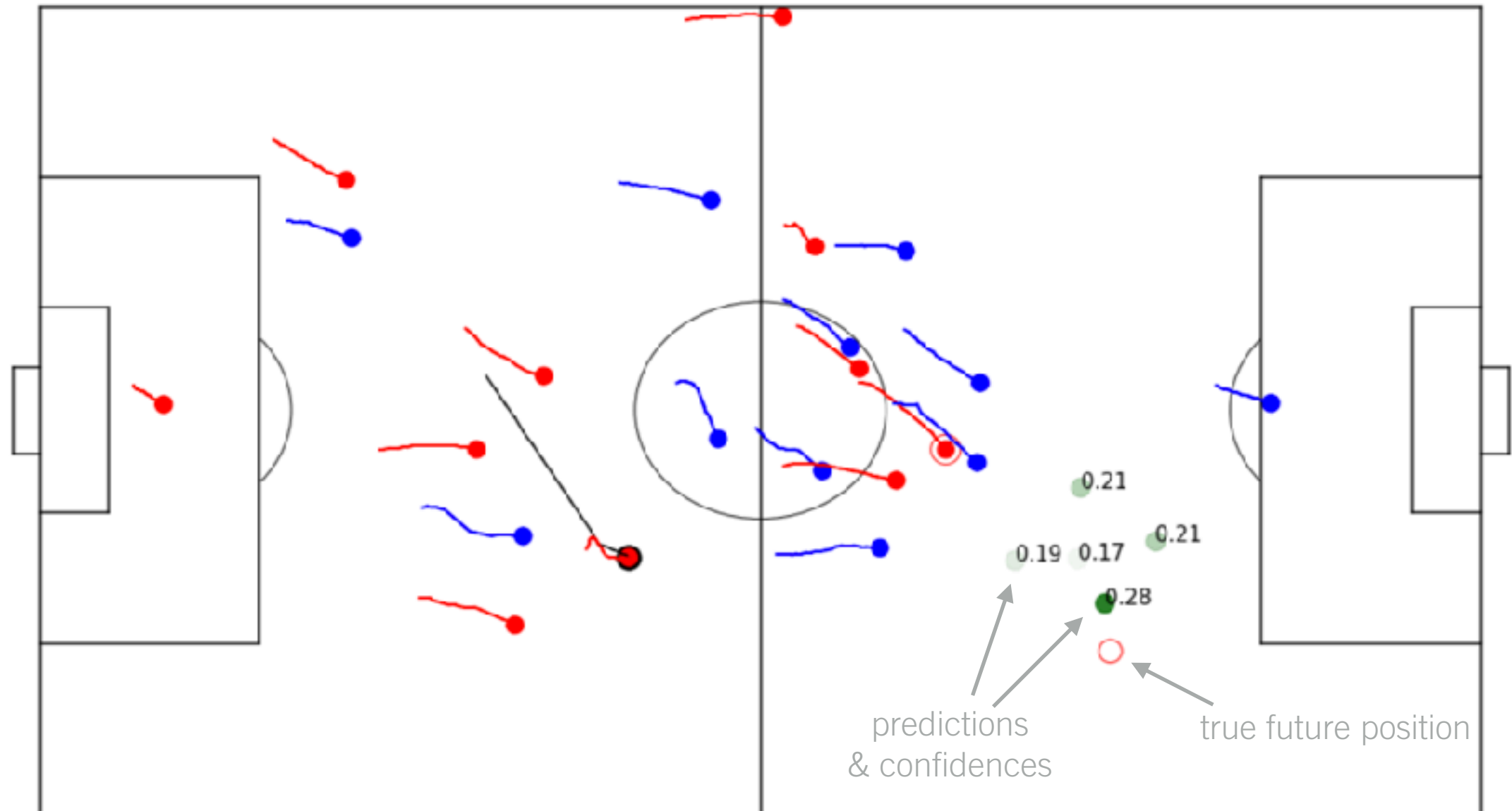
- Movement model ignores context of players:



- Including context (almost) always allows to eliminate unlikely actions and to increase predictive performance

# Contextual Movement Models

# What do we want?



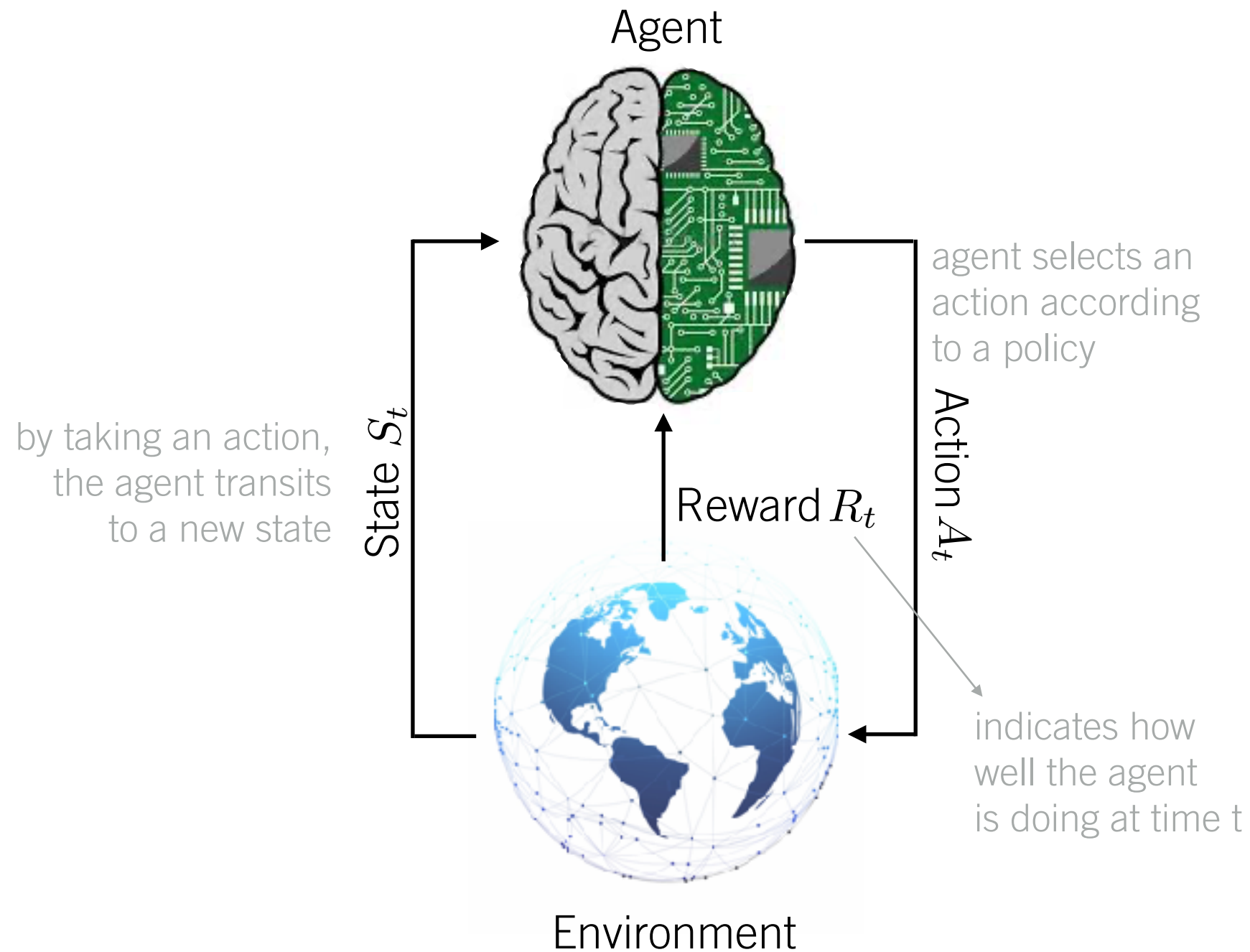


# Sequential Decision Making

- Goal: select next action to maximise the total future reward
- Problem: Actions may have long term consequences  
e.g., the mistake can already be in the very beginning and the subsequent moves are not so bad
- Reward may be delayed
- Examples:
  - Financial investment (may take time to mature)
  - Re-fueling a plane (might prevent running out of gas in some hours)

# Reinforcement Learning

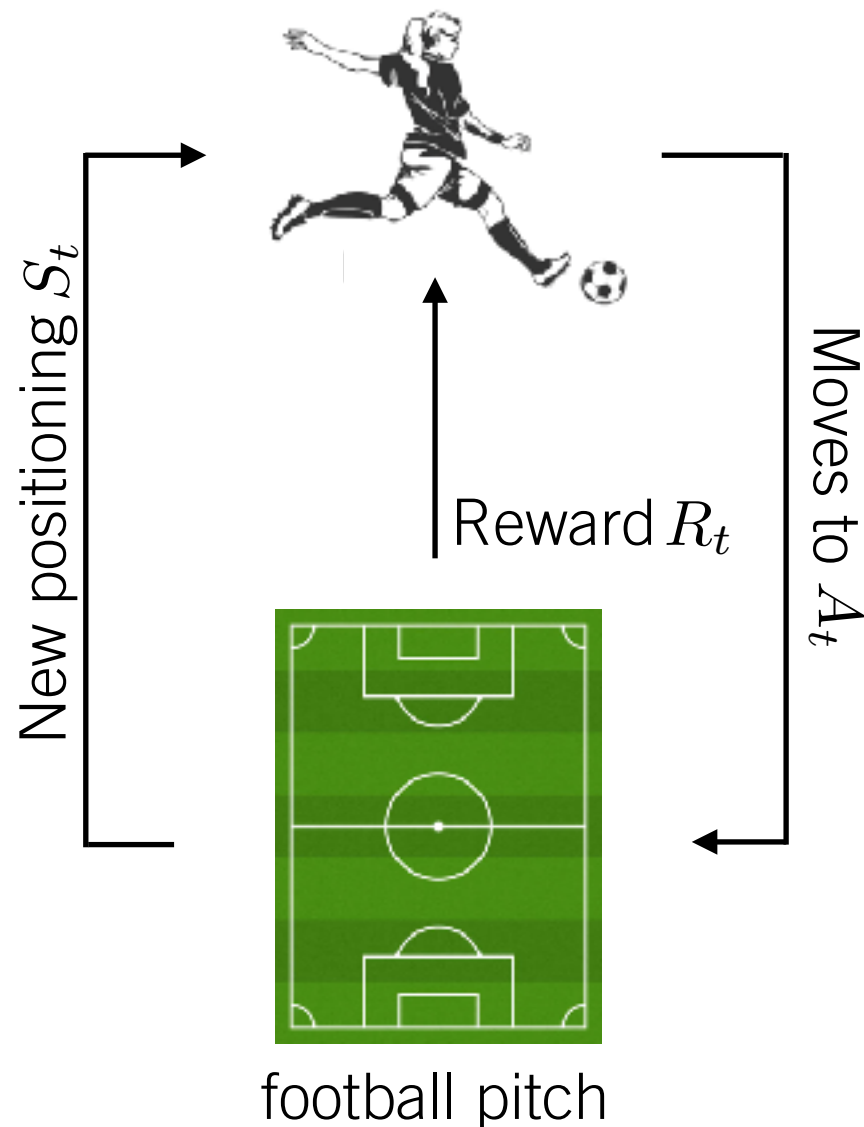
e.g., Sutton & Barto, MIT Press, 2018



# Conceptual Idea

## Player

able to see positions & direction of movement of peers & opponents but not their next actions

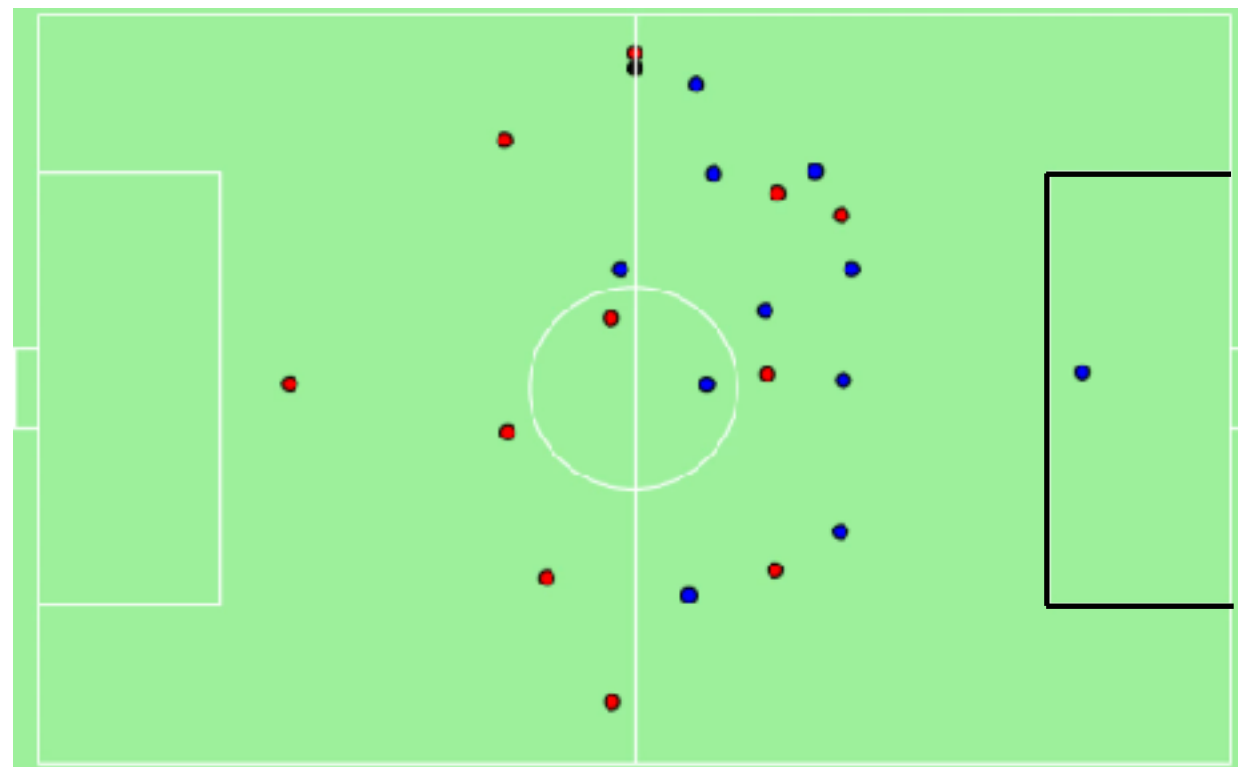


(so far) unknown:

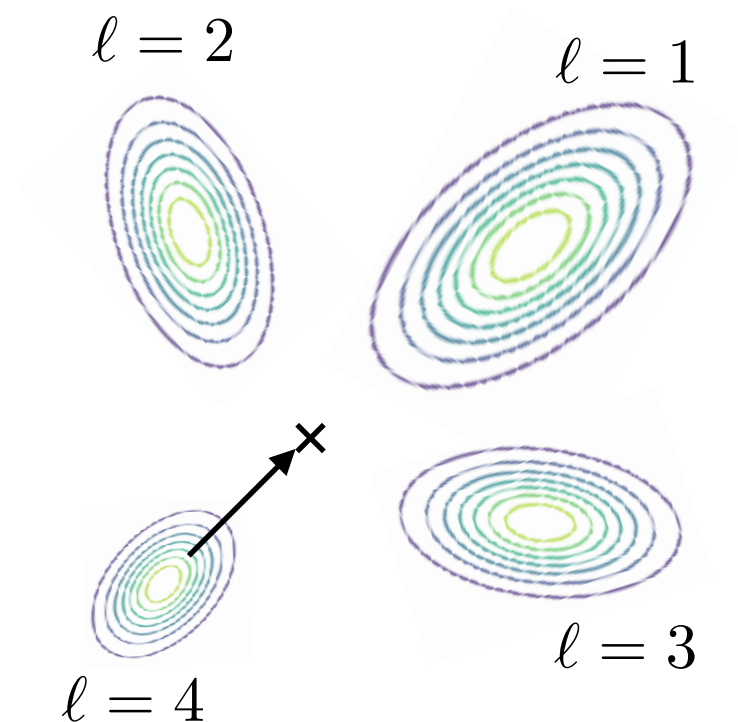
1. Reward?
2. Movement model?
3. Why does it make sense?
4. Optimisation?

# (1) Reward

- Measure of success: team enters a dangerous area
- Example: entering box vs loosing ball before  
any other measure of success possible (e.g., final 25m of pitch, goal, shot on target, etc.)



# Possible Movements as Gaussian Mixture



- Gaussians locate themselves to cover movement options of player depending on state (e.g., positioning of other players)

## (2) Movement Model $\pi$

- A Gaussian mixture allows for efficient sampling of possible movements for an agent independently of other agents

$$\pi(a|\mathbf{s}) = \sum_{\ell=1}^L p(\ell|\mathbf{s}, \psi_{prior}^{\ell}) \mathcal{N}(a|\mu(\mathbf{s}, \psi_{\mu}^{\ell}), \sigma(\mathbf{s}, \psi_{\sigma}^{\ell}))$$

Prior

Gaussian w/ mean and variance

- Gaussian mixture parameterised by state  $\mathbf{s}$  and shared parameters  $\psi_{prior}^{\ell}, \psi_{\mu}^{\ell}, \psi_{\sigma}^{\ell}$  across agents
- Mixture density networks (Bishop, 1994)

# Value Function

- The value function  $V_\pi(\mathbf{s})$  assigns values to states  $\mathbf{s}$

$$V_\pi(\mathbf{s}) =$$



# Value Function

- The value function  $V_\pi(\mathbf{s})$  assigns values to states  $\mathbf{s}$

Agent takes  
action  $\mathbf{a}$  in state  $\mathbf{s}$

$$V_\pi(\mathbf{s}) = \pi(\mathbf{a}|\mathbf{s})$$

# Value Function

- The value function  $V_\pi(\mathbf{s})$  assigns values to states  $\mathbf{s}$

Agent takes  
action  $\mathbf{a}$  in state  $\mathbf{s}$

Agent receives reward  $R$   
and transits to state  $\mathbf{s}'$

$$V_\pi(\mathbf{s}) = \sum_{\mathbf{a}} \pi(\mathbf{a}|\mathbf{s}) [R + \gamma V_\pi(\mathbf{s}')]$$

# Value Function

- The value function  $V_\pi(\mathbf{s})$  assigns values to states  $\mathbf{s}$

$$V_\pi(\mathbf{s}) = \pi(\mathbf{a}|\mathbf{s}) \sum_{\mathbf{s}', R} p(\mathbf{s}', R|\mathbf{s}, \mathbf{a}) [R + \gamma V_\pi(\mathbf{s}')] ]$$

Agent takes action  $\mathbf{a}$  in state  $\mathbf{s}$       Agent receives reward  $R$  and transits to state  $\mathbf{s}'$

sum over all possible outcomes  $\mathbf{s}'$

# (3) Value Function

- The value function  $V_\pi(\mathbf{s})$  assigns values to states  $\mathbf{s}$

$$V_\pi(\mathbf{s}) = \sum_a \pi(a|\mathbf{s}) \sum_{\mathbf{s}', R} p(\mathbf{s}', R|\mathbf{s}, a) [R + \gamma V_\pi(\mathbf{s}')] ]$$

Agent takes action  $a$  in state  $\mathbf{s}$       Agent receives reward  $R$  and transits to state  $\mathbf{s}'$

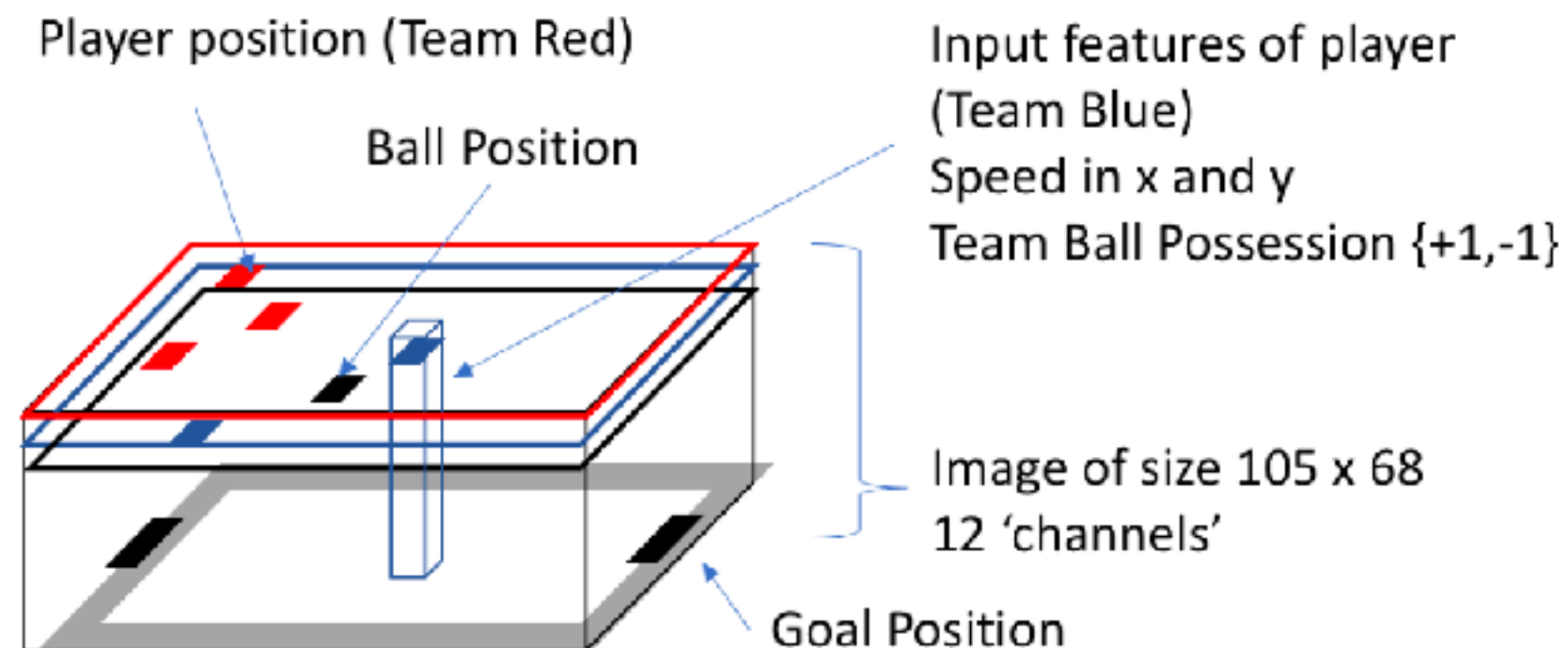
sum over all possible actions  $a$       sum over all possible outcomes  $\mathbf{s}'$

- Value function summarises all possible futures!
- Identify policy  $\pi$  with movement model!

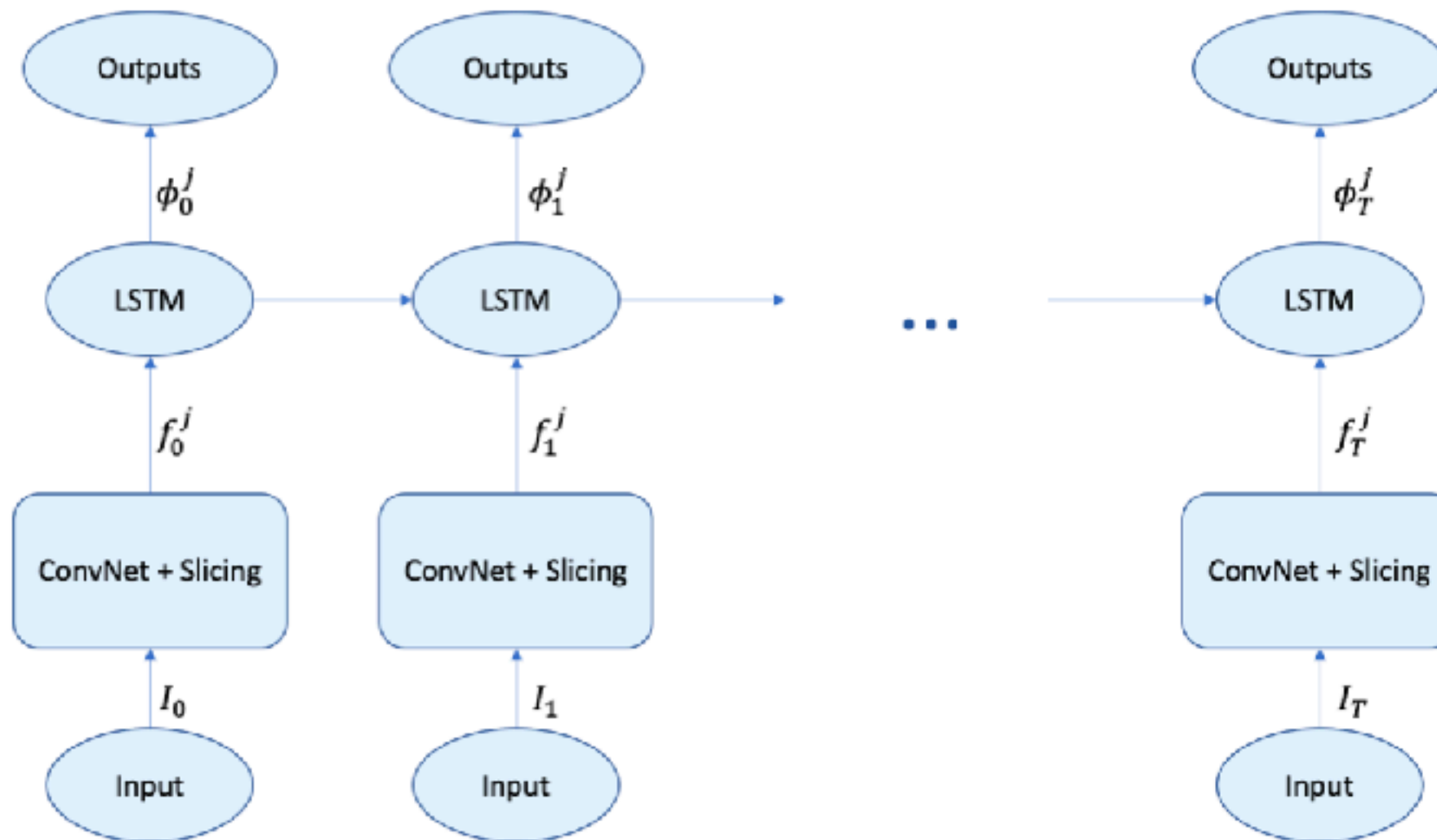
# (4) Optimisation

- Movement model and value function could be learned in a pipelined fashion but errors accumulate and difficult to control
- Solution is to learn both quantities simultaneously in a single optimisation problem

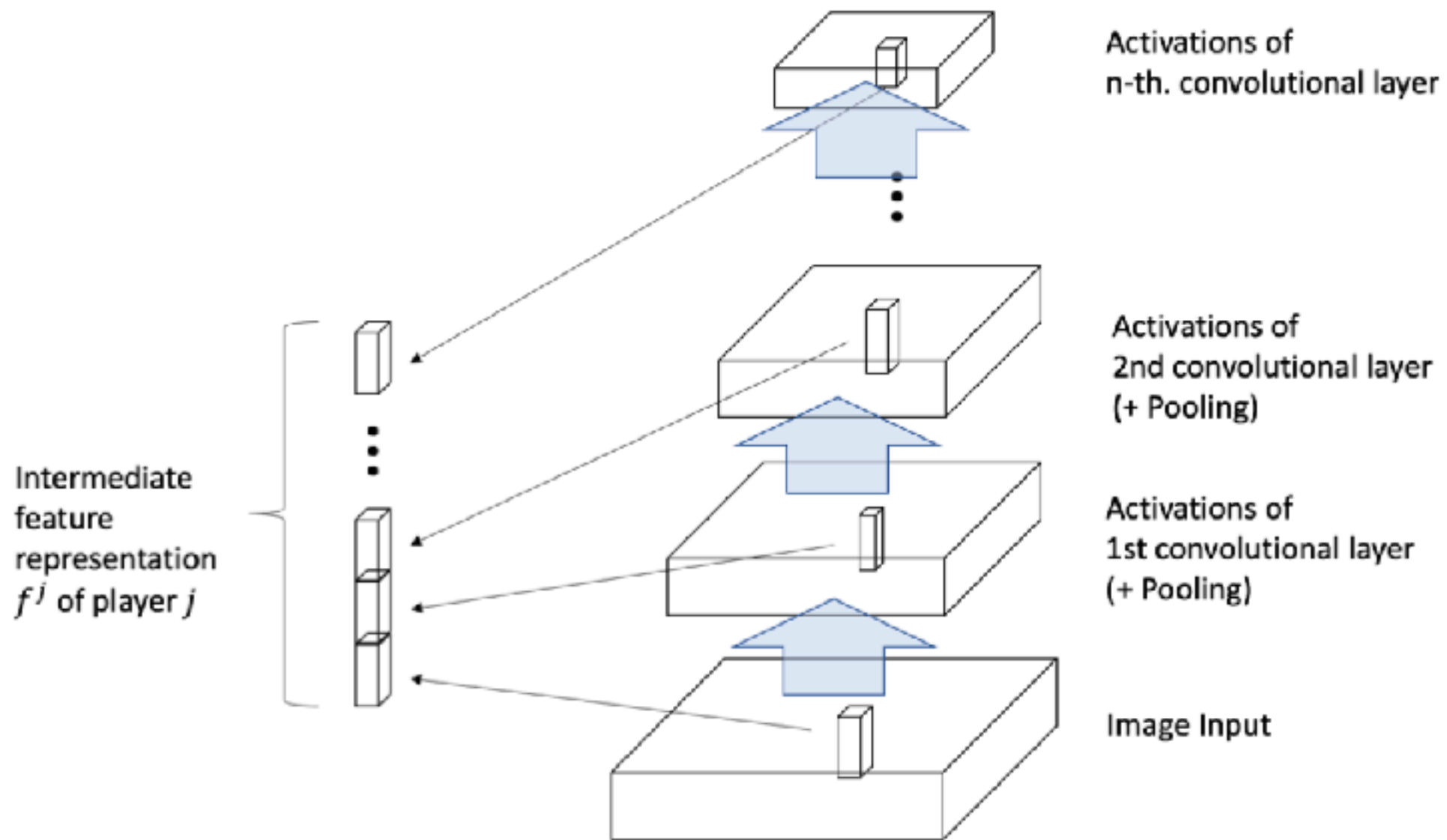
- Input:



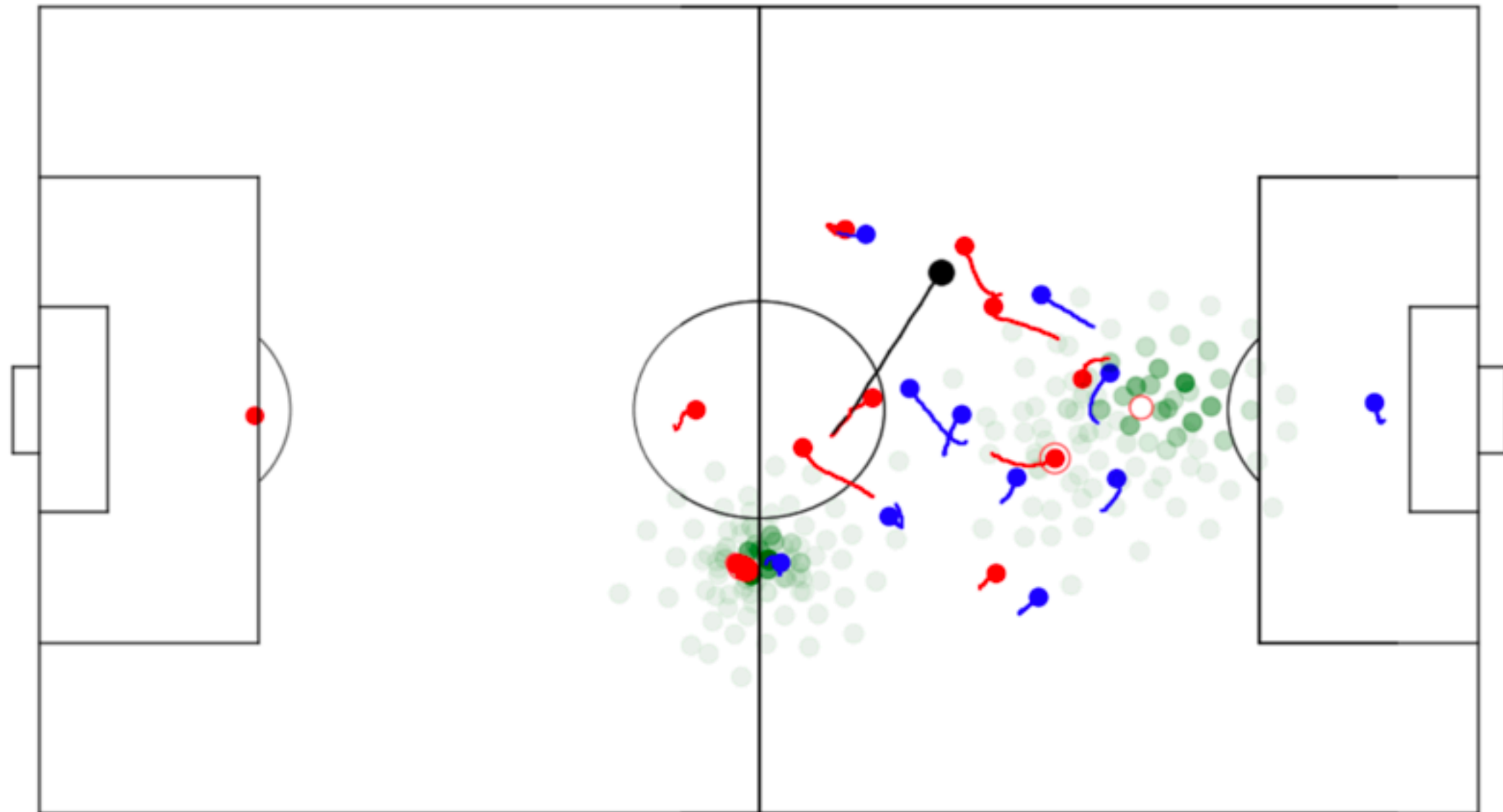
# Architecture of Deep Model



# Convolution & Representation



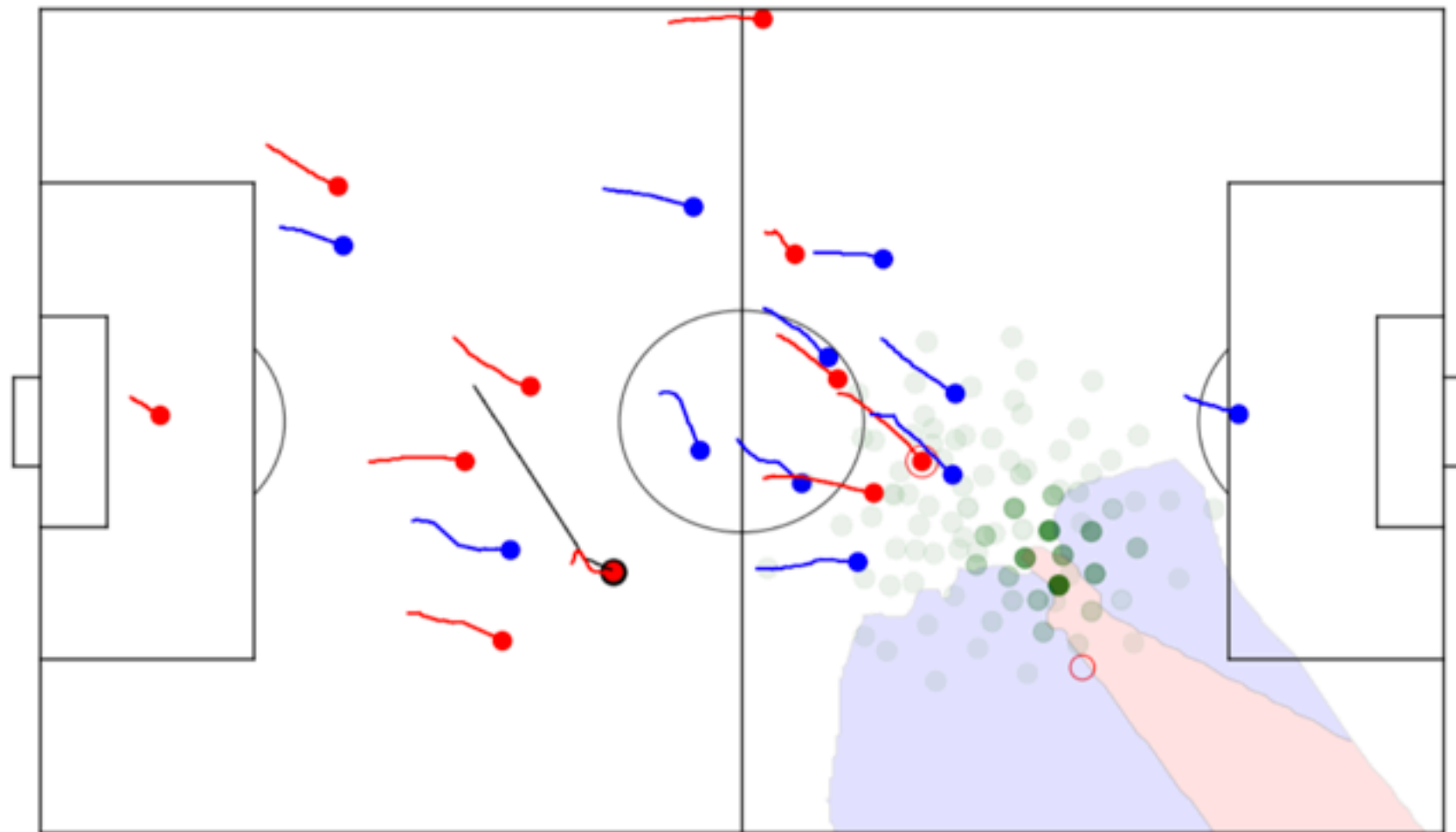
# Exemplary Predicted Movements

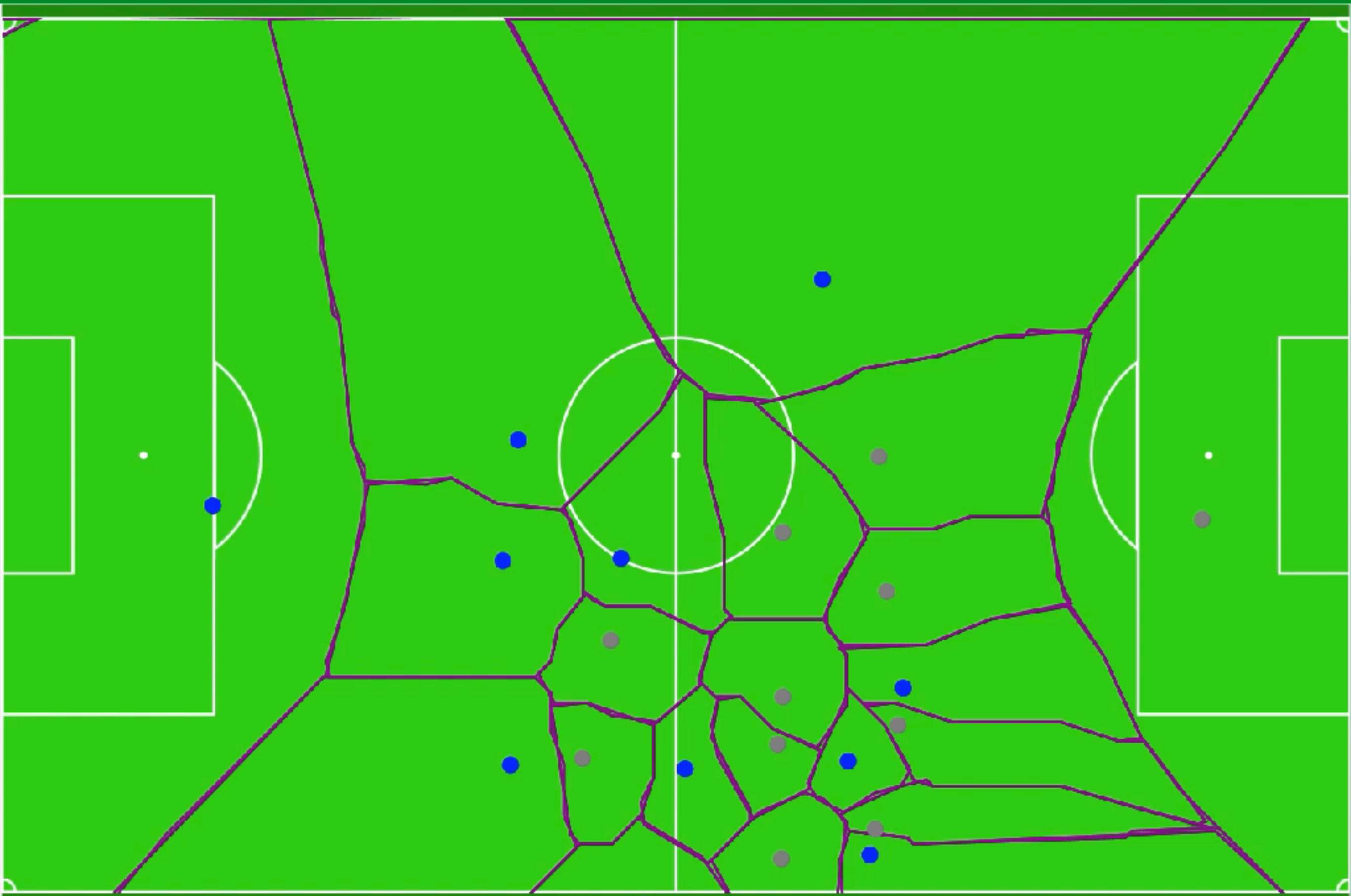




# Predicting Controlled Zones

Dick, Tavakol & Brefeld. *Frontiers in Sports and Active Living*, 3, 2021)





● ●

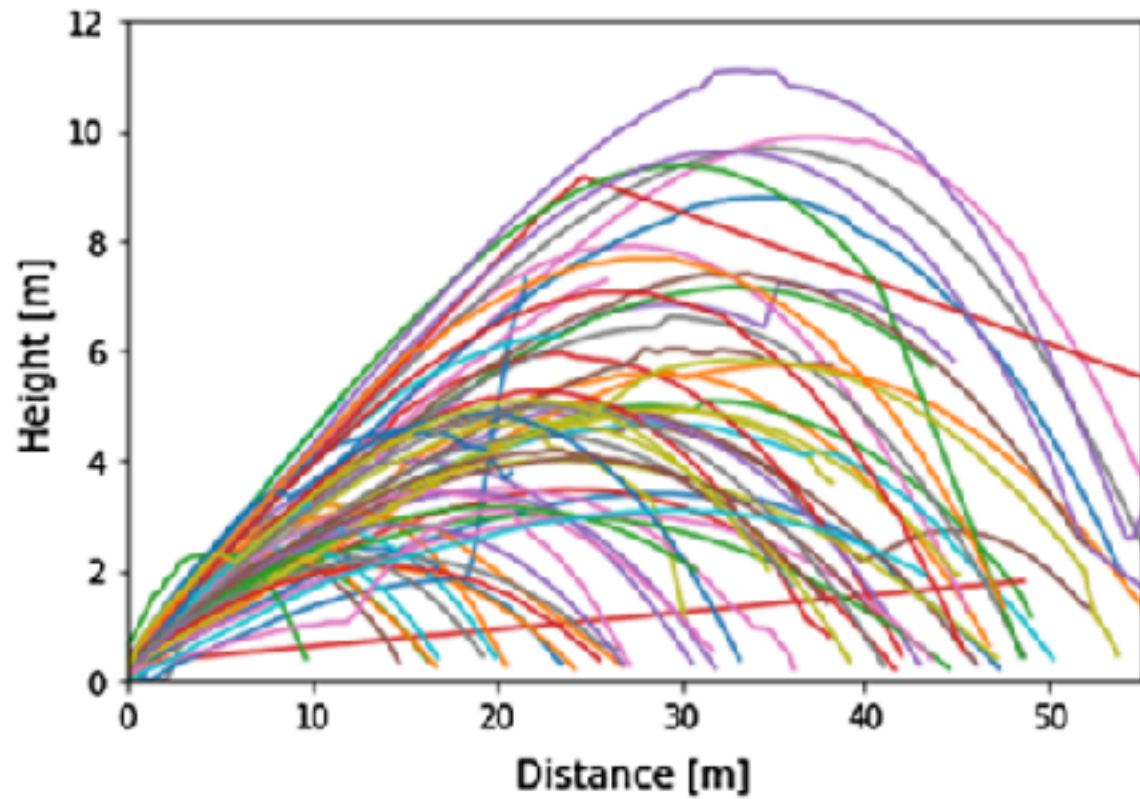
# Application: *Availability*

# Availability

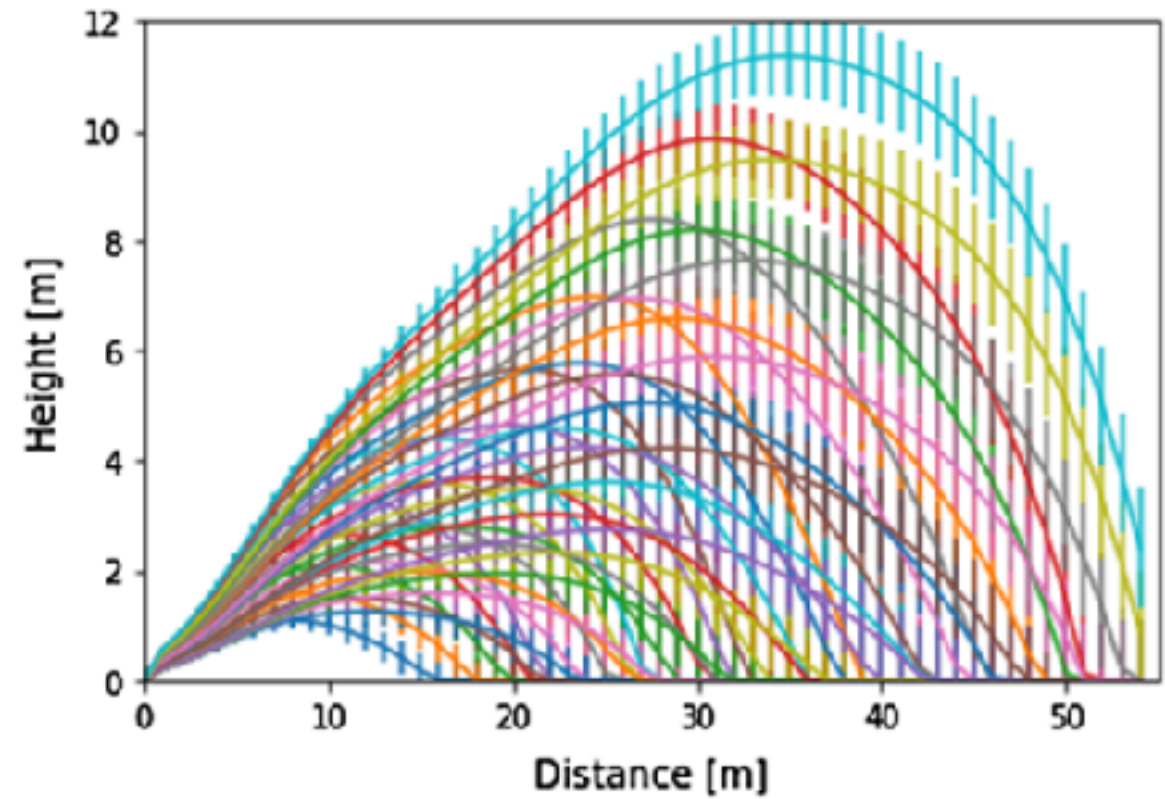
- Is player Y available for a pass?
  - How much time does the ball need to reach player Y?
  - Can X pass the ball to Y in a given situation?  
e.g., Y shadowed by another player, blocked path, difficult angle, technical skills, etc.
  - Can any opponent player Z intercept the ball?  
e.g., distance to X, distance to path of ball, reaction time, etc.
  - Does Y have enough time to control the ball?  
e.g., distance to closest opponent player(s), technical skills, difficulty of pass, etc.

# Ball dynamics

U. Dick, D. Link, and U. Brefeld. DAMI, 2022



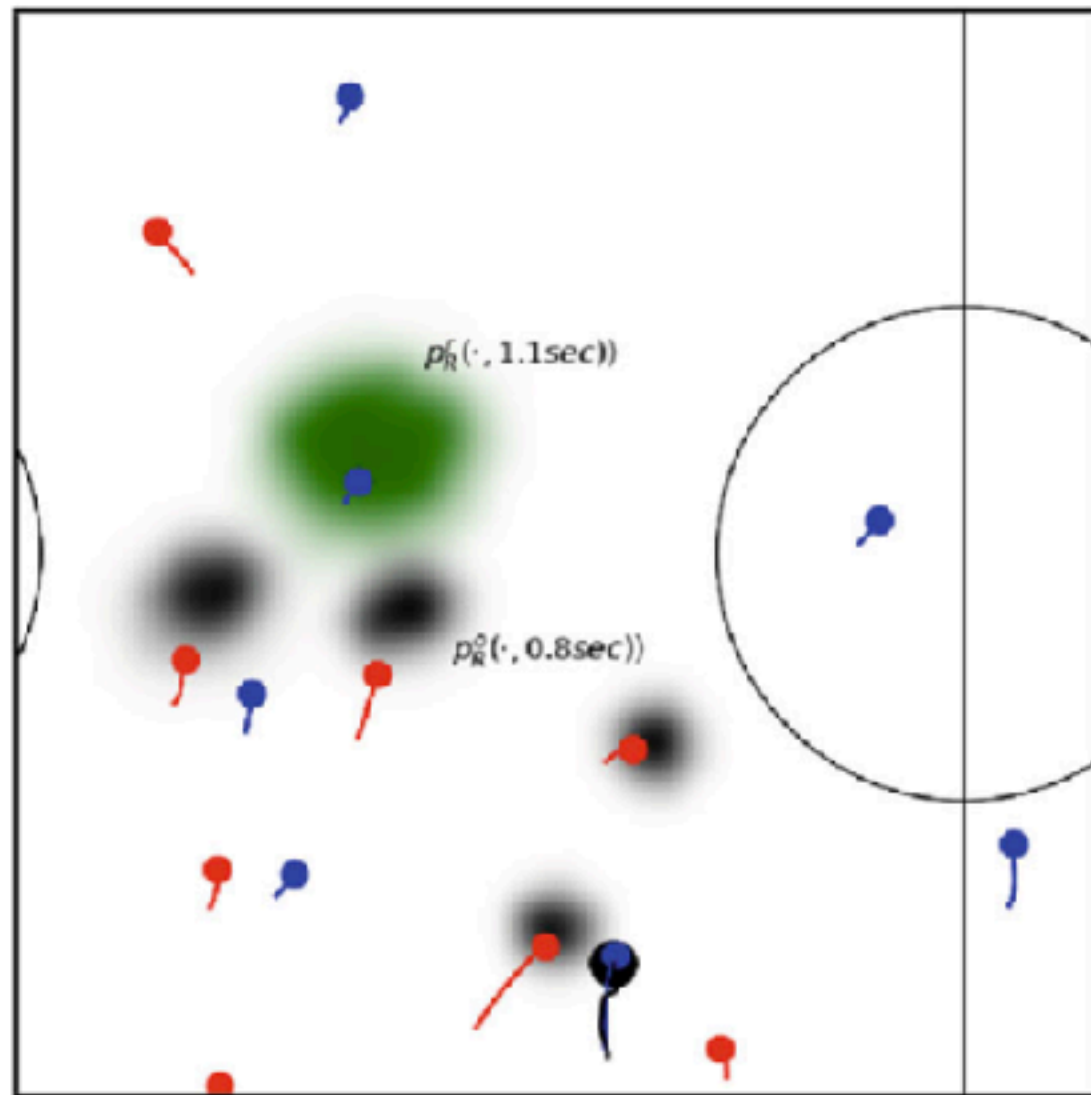
data



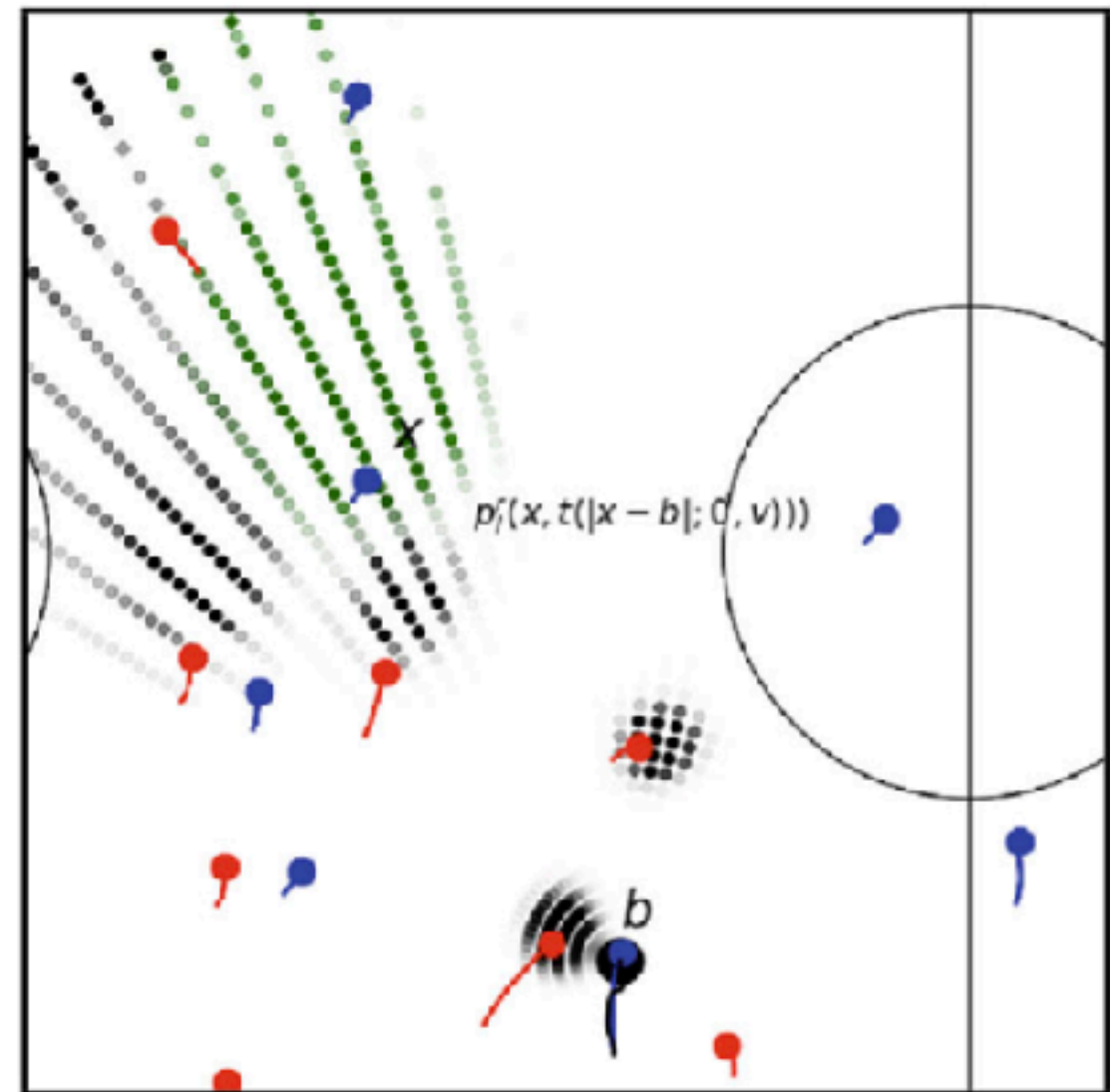
model

# Example

U. Dick, D. Link, and U. Brefeld. DAMI, 2022



reachability likelihoods

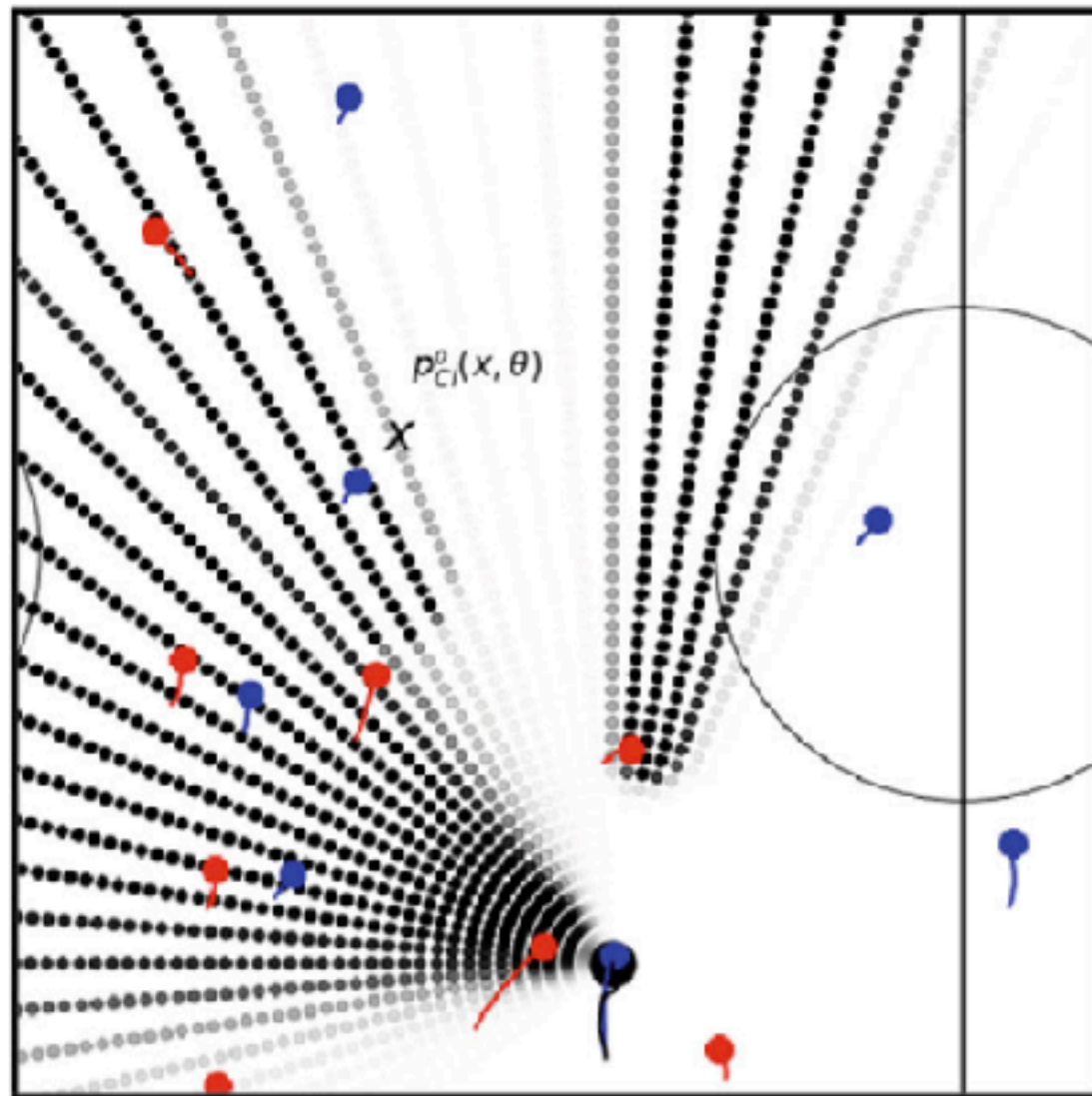


interception likelihoods

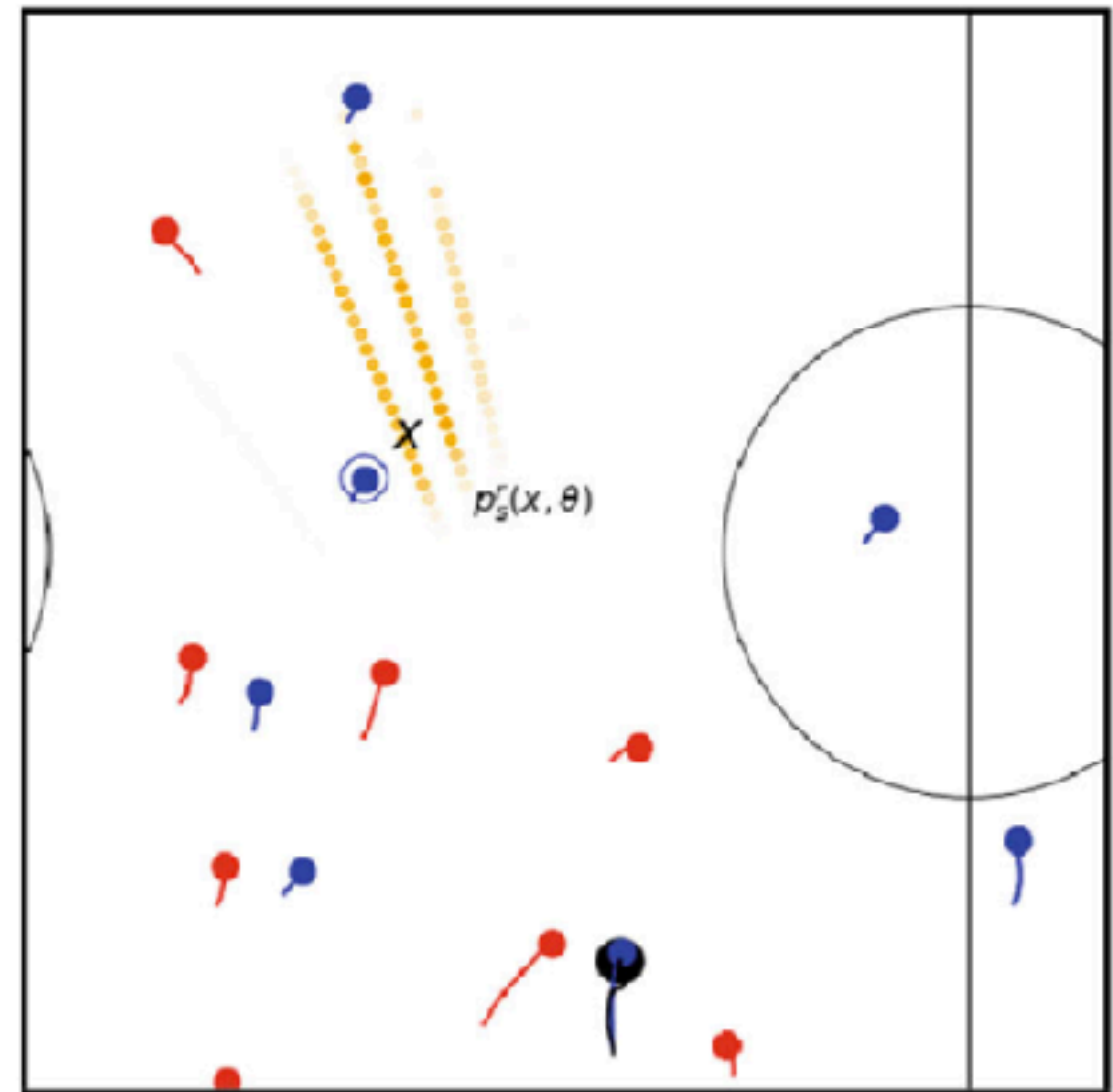


# Example (cont'd)

U. Dick, D. Link, and U. Brefeld. DAMI, 2022



interception likelihoods



success likelihoods

# Availability





# Expert Ratings

U. Dick, D. Link, and U. Brefeld. DAMI, 2022

	Obs1	Obs2	Obs3	Obs4	Model	#
-1	-0.25	0.25	0.12	0.12	0.12	8
+1	1.33	1.46	1.24	1.32	1.77	48
AUC	0.826	0.814	0.729	0.787	0.889	

scores in  $\{-2:-1,0,1,2\}$

50:50 chance to get the ball,

player should be able to receive the ball safely  
if the passing player does not make a terrible mistake.

player has a good chance to receive the ball,  
but there is maybe a small interception chance  
for an opponent.

- Expert ratings strongly correlated with model predictions
- On average model outperforms human experts

# Ranking of players

Player	Availability	Success	Count	Difference
S. Rudy	0.898	0.944	412	0.046
K. Papadopoulos	0.889	0.935	367	0.046
J. Kimmich	0.907	0.945	855	0.038
A. Vidal	0.912	0.946	405	0.034
D. Caligiuri	0.861	0.894	500	0.033
D. Alaba	0.921	0.950	515	0.029
C. Tolisso	0.921	0.950	458	0.029
G. Sakai	0.874	0.902	540	0.028
N. Süle	0.937	0.965	510	0.028
B. Stambouli	0.888	0.916	392	0.028

350 passes, 65 players from FC Bayern Munich, Hamburger SV, TSG 1899 Hoffenheim, FC Schalke 04, and SG Eintracht Frankfurt

# Pattern Detection

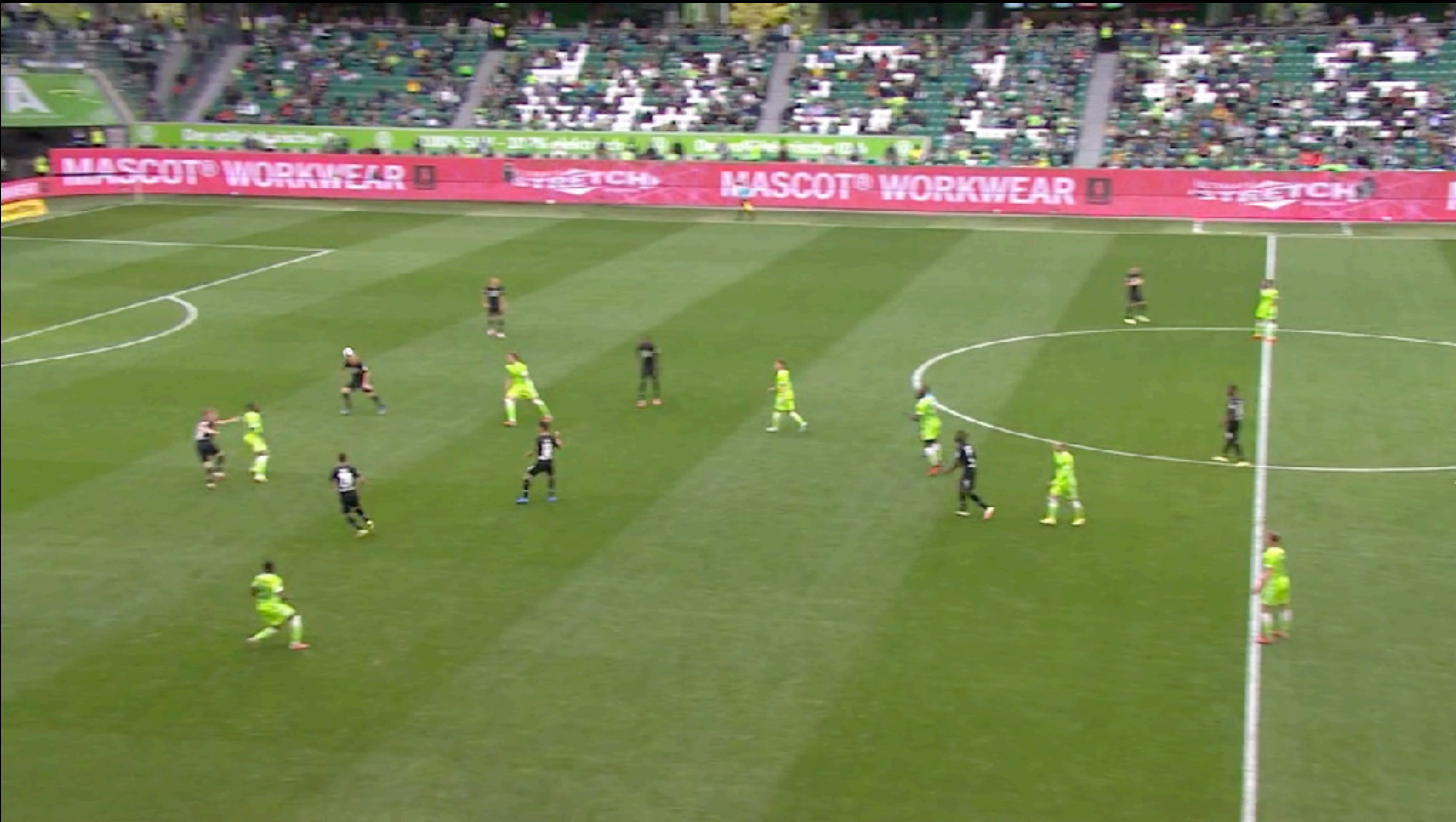
# Daily work at a club

- Video is still the main source of information
- Video analysts watch hours of video footage to prepare for the next match (e.g., scout opponents, find good/bad situations in own team, ...)
- Can we identify situations of interest (i.e., patterns of interest) automatically in a large number of matches?

# Theory & Practice

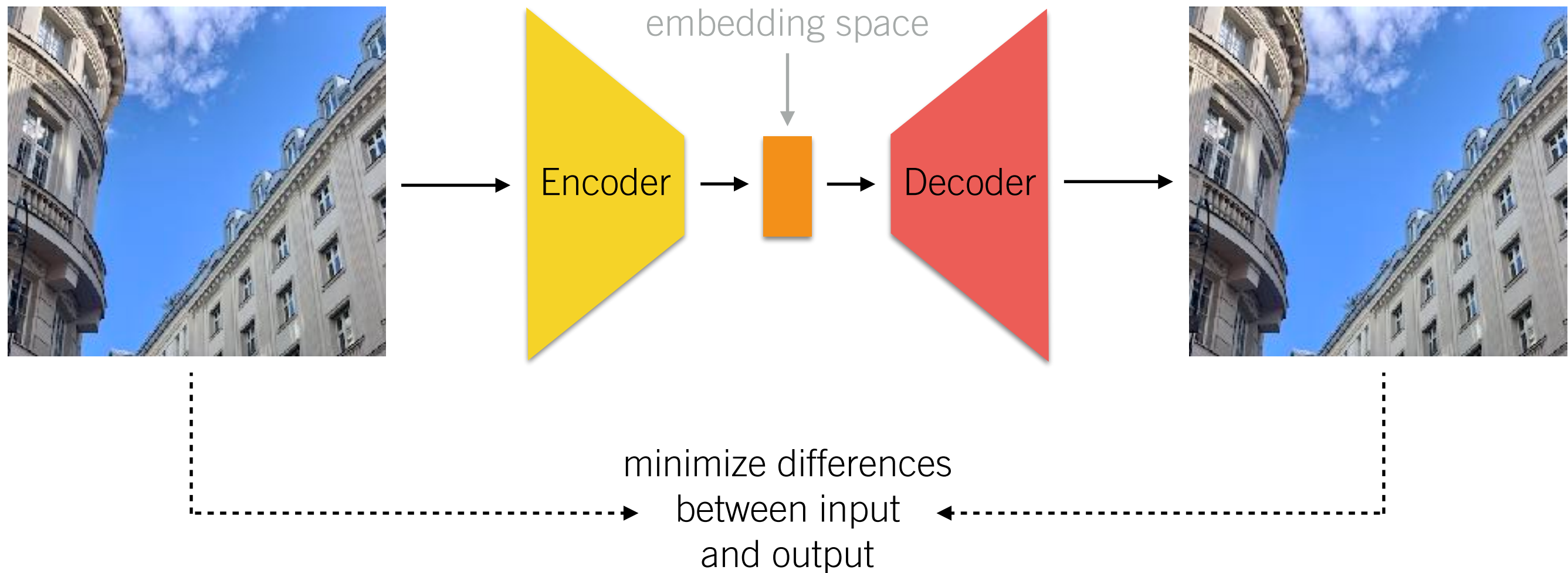
- Theory: Supervised classification problem where labelled instances  $(x_1, y_1), \dots, (x_N, y_N)$  are given
- Practice: Labels  $y_n$  do not exist! We only have  $x_n$  but very many thereof
- Solution: Semi-supervised with labelled  $(x_1, y_1), \dots, (x_N, y_N)$  and unlabelled situations  $x_{N+1}, \dots, x_{N+M}$  where  $N \ll M$





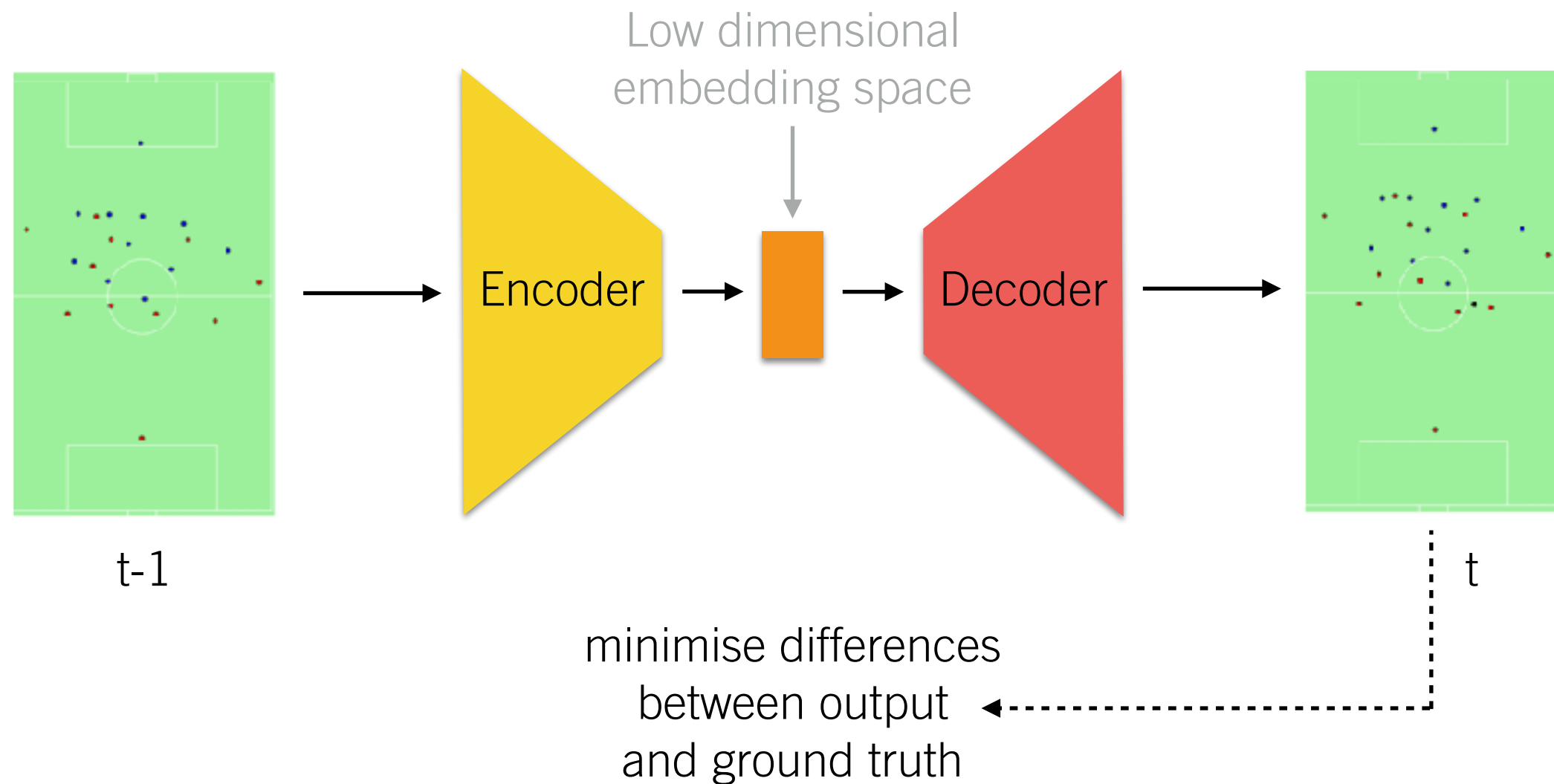
# (Variational) Autoencoders

e.g., Hinton & Salakhutdinov (2006); Kingma & Welling (2013)



# AEs as Movement Model

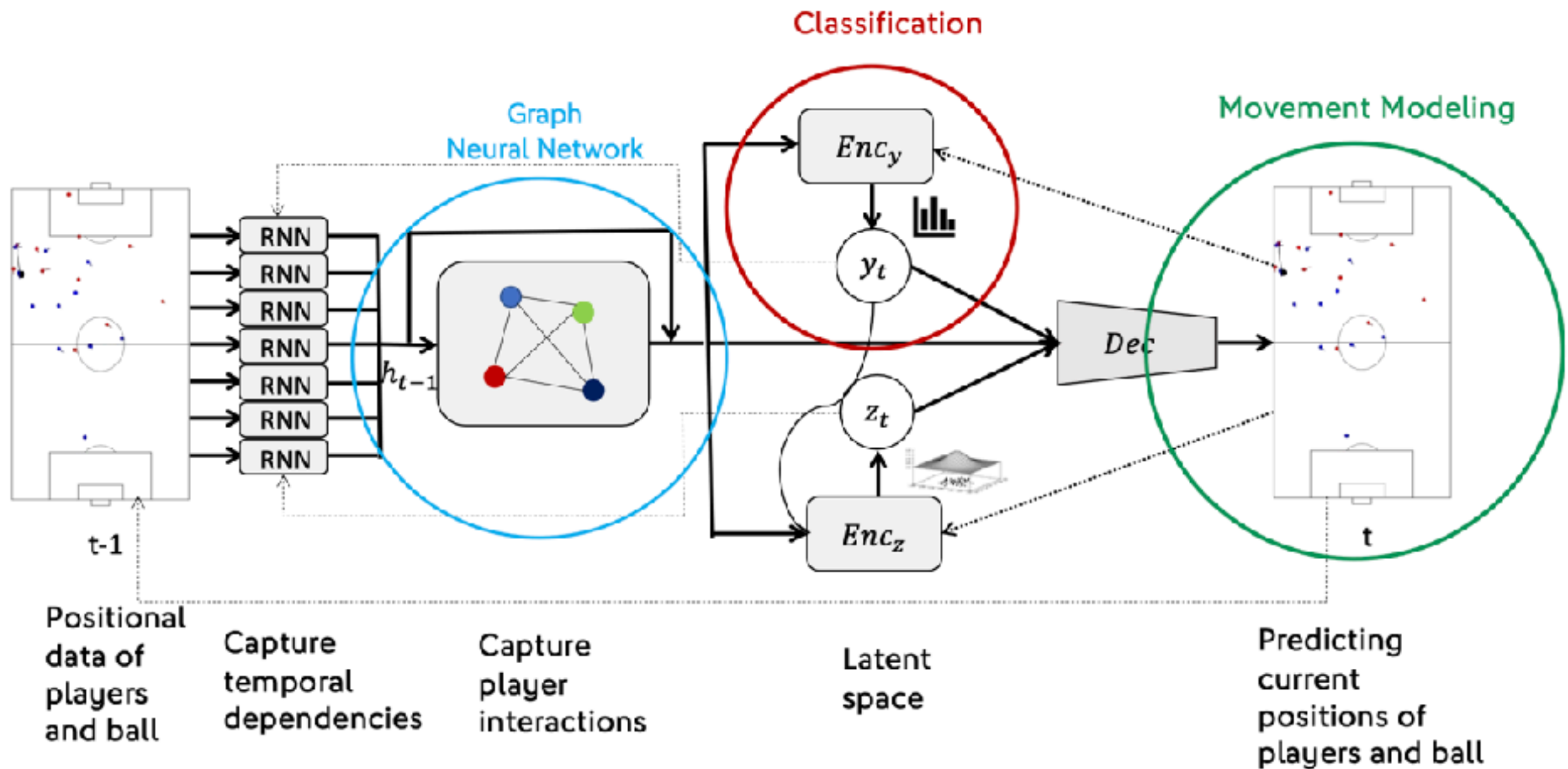
(conceptual approach)





# Semi-supervised Variational AE

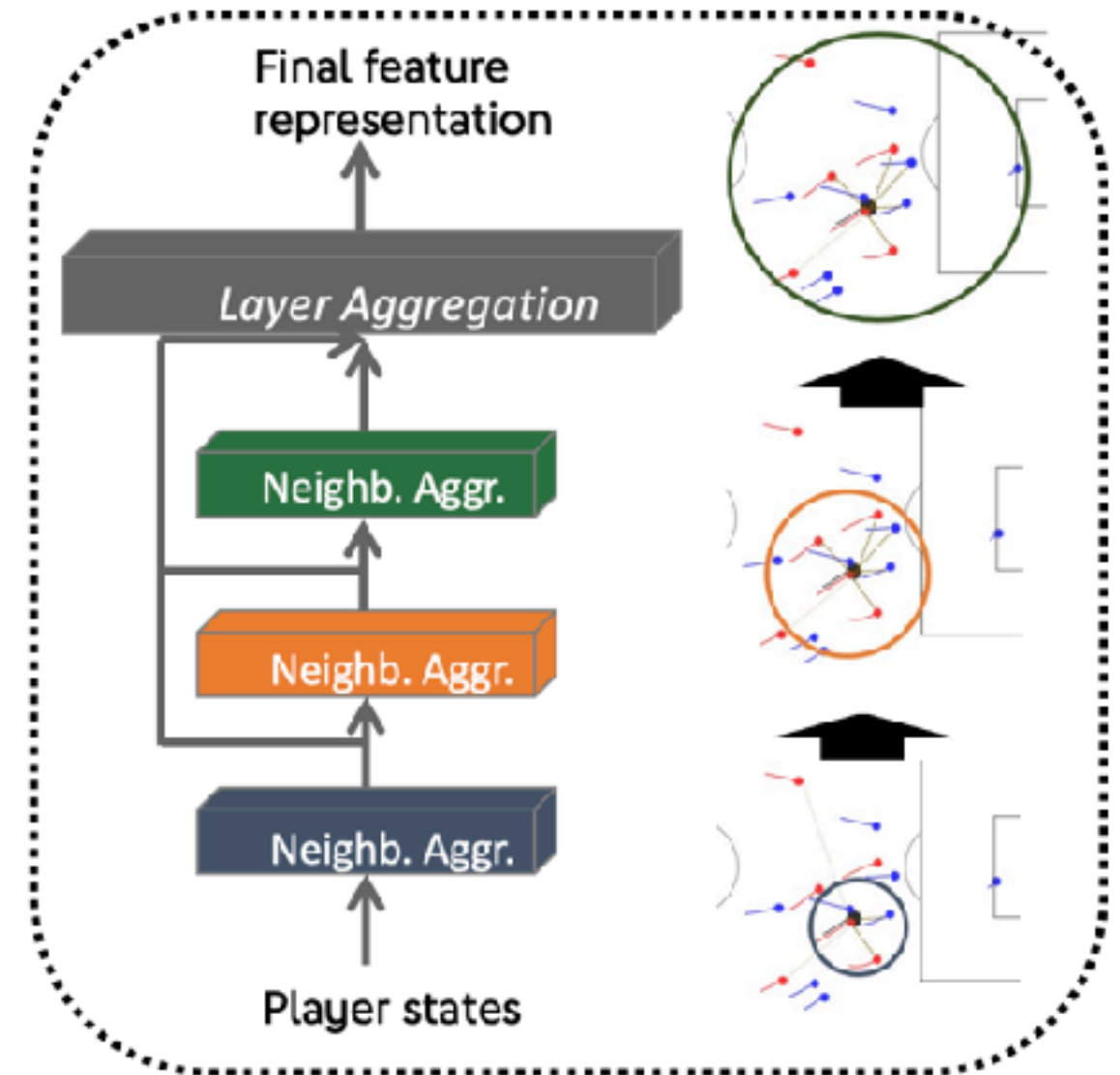
G. Anzer, P. Bauer, U. Brefeld, D. Fassmeyer, SSAC, 2021



# GNN Design

G. Anzer, P. Bauer, U. Brefeld, D. Fassmeyer, SSAC, 2021

- Adding depth to the network increases receptive field
- Skip connections allow to adaptively accommodate information from different levels of granularity
- That is, players can capture immediate player influences and holistic team strategies



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# Empirical Results

G. Anzer, P. Bauer, U. Brefeld, D. Fassmeyer, SSAC, 2021

Task	Model	AUC	F1
Overlapping runs	DetNet	0.62	—
	Rule-based	—	0.31
	Ours	0.93	0.4
Chance w/out shot	DetNet	0.69	—
	Ours	0.98	0.37

- Universally applicable for spatiotemporal pattern detection
- Makes use of only a few labelled and many unlabelled situations (cmp. w/ fully supervised methods)



# In Short:

- Often, answering complex questions requires:

- A computational model of what is possible

e.g., movement model, rays representing all possible passes, ...

- A computational representation of what happened

e.g., an embedding for similar situations

- A computational understanding of alternative options of every player in any situation

e.g., an embedding for similar situations

- A computational way to compute optimal actions

e.g., via reinforcement learning / imitation learning / behavioural cloning


- A computational value of how good observed actions are wrt to the optimal action

e.g., difference between value of optimal and observed action

1st part

2nd part

# Summary

- Contextual movement models are key to analysing tracking data and integral parts when dealing with more sophisticated problems, e.g., actions, availability, pattern detection,...
- Depending on desired application, there are different ways to incorporate a movement model in the training process
- Web: [ml3.leuphana.de/ulf.html](http://ml3.leuphana.de/ulf.html) 

Many thanks to:





# The Group

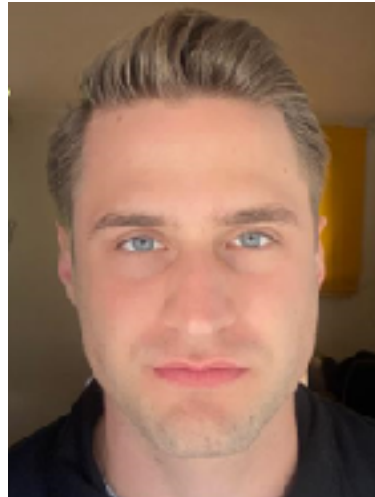
Daniel Bengs



Eraldo Fernandes



Dennis Fassmeyer



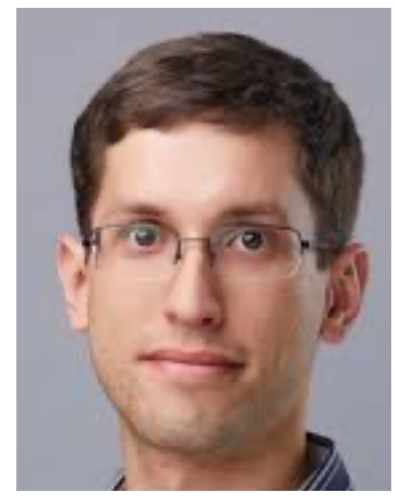
Jenny Matthiesen



Kai Neubauer



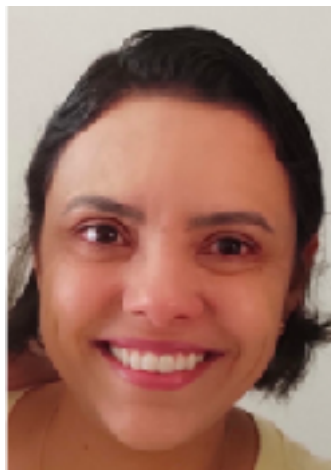
Samuel Fadel



Tino Paulsen



Valeria Reis



Yannick Rudolph



Madlen Schmalz



Sabrina Bergmann



Ulf Brefeld

