Towards a Qualitative Representation of Movement

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Outline

- **Introduction**
- **Related work**
- **Qualitative representation of movement**
  - Spatio-temporal primitives
  - Classification of movement
    - Movement outside a reference entity
    - Movement on the boundary of a reference entity
    - Movement inside a reference entity
- **Conceptual neighbor diagram**
- **Conclusion**

Understanding movement patterns

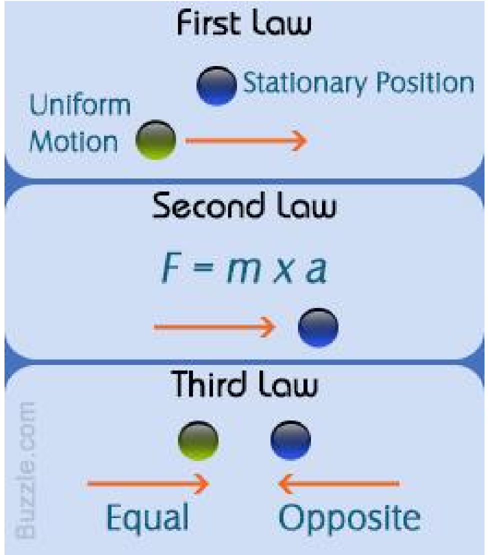
- **Movement** is a vital element of all organisms and many spatio-temporal processes that happen in **large-** and **small-scale spaces**.
- A better understanding of movement patterns is a key issue for many GIS application areas:
  - behavioral ecology
  - human mobility
  - traffic management
  - environmental hazards
  - ...

Research Objectives

- Taking a relative point of view of the movement of two given entities, **movement** being considered by giving a particular importance on the **boundary** of the one that might be considered as predominant or as a reference.
- We intend to provide an intuitive set of modeling primitives that support the **qualitative** representation of movement, with the potential advantage of providing a systematic tool for **investigating** and **reasoning** over qualitative movements.

Quantitative Approaches

- Newton's laws of motion
  - First law
  - Second law
  - Third law
- Theory of relativity
  - Special relativity
  - General relativity
- Kinematics
- ...



A Qualitative Perspective

- bridge the gap between **formal** and **linguistic descriptions of movement**
- based on **a finite set of relations**
- efficient when precise information is **not available** or **not necessary**
- that can take into account **configurations with imprecise information**

Related Work

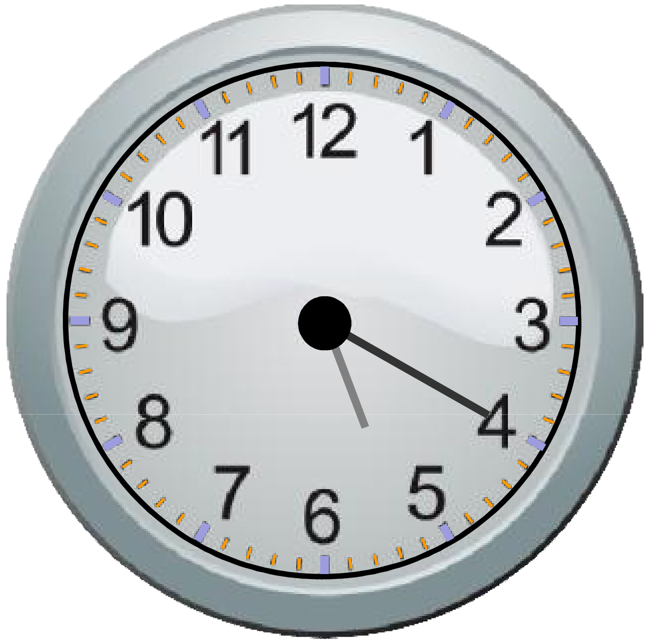
- Qualitative theory of motion (Galton,1995)
- Movement semantic
  - Abstractions from textual documents (Stewart Hornsby and Li, 2009)
  - Computational semantics (Pustejovsky and Moszkowicz, 2011)
- Qualitative Calculus
  - Qualitative Trajectory Calculus (Van de Weghe, 2004)
  - 9I+ calculus (Kurata and Egenhofer, 2007)
  - Relative-based formalism extended to location, speed and acceleration (Noyon *et al.*, 2007)
  - *RCC*8 & Temporal algebra model (Muller, 1998)
  - Directional-based formalism (Gottfried, 2011)
- …

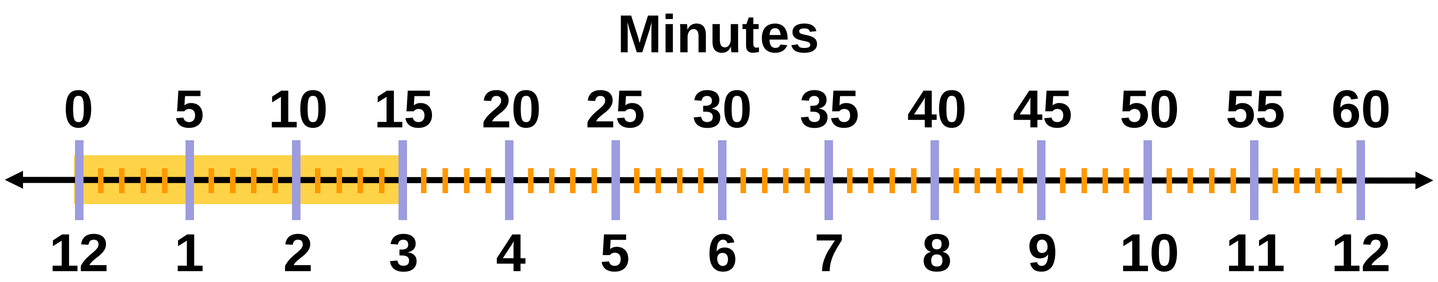
Qualitative representation of movement

- Spatial primitives
  - **simply connected planar regions** in the Euclidean plane;
  - the configurations identified correspond to **monotonic** and **continuous movements** valid over a given temporal of time;
  - we assume that the **boundaries** of the entities modeled are **well-defined**, as well as the **topological relationships** and **relative distance** between them.
- Spatio-temporal primitives
  - Time interval
  - *RCC*8 algebra
  - Relative distance between moving entities
- Classification of movement
  - Movement **outside** a reference entity
  - Movement **on the boundary** of a reference entity
  - Movement **inside** a reference entity

Time interval

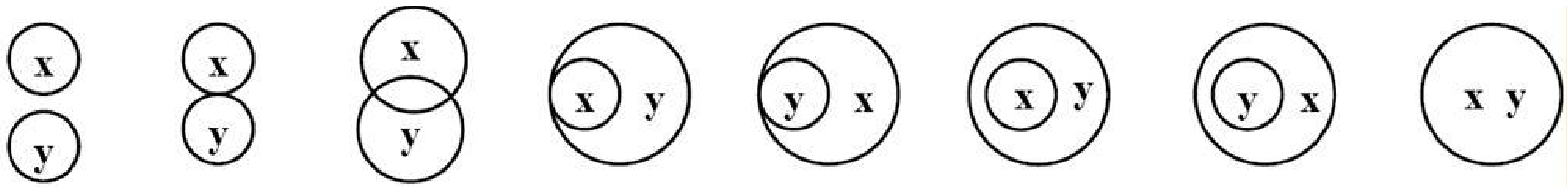
- A **time interval** *T* is a definite length of time marked off by two instants that passes during an activity.





RCC (Regional Connection Calculus) algebra

- ***DC***(x, y): x is disconnected from y
- ***EC***(x, y): x is externally connected to y
- ***PO***(x, y): x partial overlaps y
- ***TPP***(x, y): x is a tangential proper part of y
- ***TPPI***(x, y): x has y as a tangential proper part
- ***NTPP***(x, y): x is a non-tangential proper part of y
- ***NTPPI***(x, y): x has y as a non-tangential proper part
- ***EQ***(x, y): x is equal to y



DC(x, y) *EC*(x, y) *PO*(x, y) *TPP*(x, y) *TPPI*(x, y) *NTPP*(x, y) *NTPPI*(x, y) *EQ*(x, y)

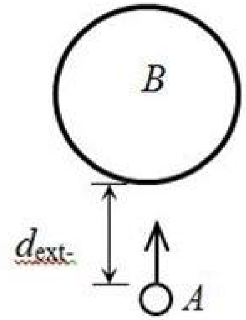
Relative distance between moving entities

- *D*: **Relative distance** between a moving entity *A* and a reference entity *B* *o*ver a time interval *T*.
- *d:* the **minimum distance between the boundary** of *A* and the **boundary** of *B* at a given time *t*
  - d_{ext+}: *D* is **continuously increasing outside** *B* over a given temporal interval *T* (i.e, for all *t* of *T*)
  - d_{ext-}: *D* is **continuously decreasing outside** *B* over a given temporal interval *T*
  - $d_{ext=}$: *D* is **constant outside** *B* over a given temporal interval *T*
  - d_0: *D* is **null** over a given temporal interval *T*
  - d_{int+}: *D* is **continuously increasing inside** *B* over a given temporal interval *T*
  - d_{int-}: *D* is **continuously decreasing inside** *B* over a given temporal interval *T*
  - $d_{int=}$: *D* is **constant inside** *B* over a given temporal interval *T*

Classification of movement

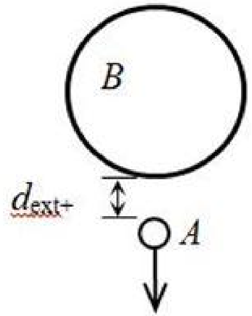
- Movement outside a reference entity
  - ***Approach***$((A, B), D, T)$: A moving entity A is approaching a reference entity B over a time interval T. For all $t \in T$, $DC(A, B)$ holds and the distance relationship D is decreasing outside B over T:

    $$Approach((A, B), D, T) \equiv Holds(DC(A, B), d_{ext-}, T)$$



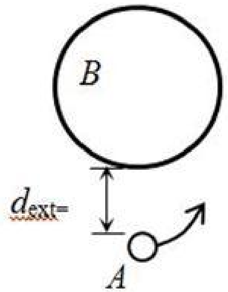
  - ***Leave***$((A, B), D, T)$: A moving entity A is leaving a reference entity B over a time interval T. For all $t \in T$, $DC(A, B)$ holds and the distance relationship D is increasing outside B over T:

    $$Leave((A, B), D, T) \equiv Holds(DC(A, B), d_{ext-}, T)$$



  - ***AroundOutside***$((A, B), D, T)$: A moving entity A is either moving around or static outside a reference entity B over a time interval T. For all $t \in T$, $DC(A, B)$ holds and the distance relationship D is constant outside B over T:

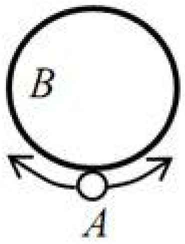
    $$AroundOutside((A, B), D, T) \equiv Holds(DC(A, B), d_{ext-}, T)$$



Classification of movement

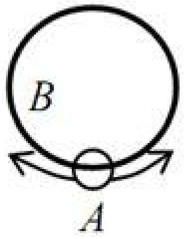
- Movement on the boundary of a reference entity
  - ***Touching***$((A, B), D, T)$: A moving entity A is touching outside the boundary of a reference entity B over a time interval T. For all $t \in T$, $EC(A, B)$ holds and the relative distance D is d_o over T:

    $$Touching((A, B), D, T) \equiv Holds(EC(A, B), d_o, T)$$



  - ***Overlapping***$((A, B), D, T)$: A moving entity A is overlapping the boundary of a reference entity B over a time interval T. For all $t \in T$, $PO(A, B)$ holds and the relative distance D is d_o over T:

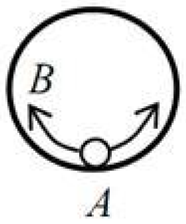
    $$Overlapping((A, B), D, T) \equiv Holds(PO(A, B), d_o, T)$$



Classification of movement

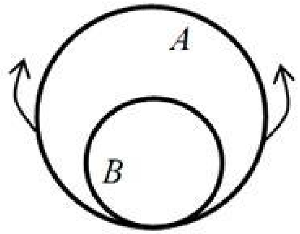
- Movement on the boundary of a reference entity
  - ***CoveringBy***$((A, B), D, T)$: A moving entity A is touching inside the boundary of a reference entity B over a time interval T. For all $t \in T$, $TPP(A, B)$ holds and the relative distance is d_O over T :

$$CoveringBy((A, B), D, T) \equiv Holds(TPP(A, B), d_O, T)$$



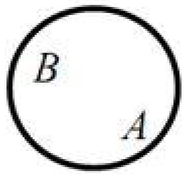
  - ***Covering***$((A, B), D, T)$: A moving entity A is touching outside the boundary of a reference entity B over a time interval T. For all $t \in T$, $TPPI(A, B)$ holds and the relative distance D is d_O over T :

$$Covering((A, B), D, T) \equiv Holds(TPPI(A, B), d_O, T)$$



  - ***Equaling***$((A, B), D, T)$: A moving entity A equals a reference entity B over a time interval T. For all $t \in T$, $EQ(A, B)$ holds and the relative distance D is d_O over T :

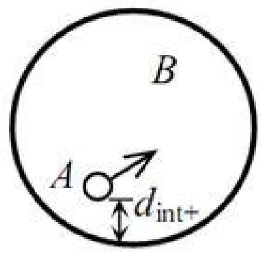
$$Equaling((A, B), D, T) \equiv Holds(EQ(A, B), d_O, T)$$



Classification of movement

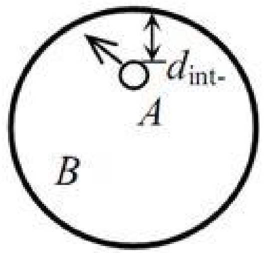
- Movement inside a reference entity
  - ***MovetoInterior***$((A, B), D, T)$: When a moving entity A is *NTPP* to a reference entity B and leaving the boundary of B over a time interval T. For all $t \in T$, $NTPP(A, B)$ holds and the relative distance D is increasing inside B over T:

    $$MovetoInterior((A, B), D, T) \equiv Holds(NTPP(A, B), d_{int+}, T)$$



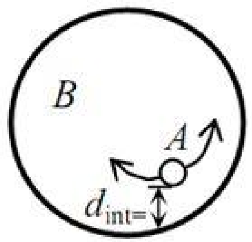
  - ***MovetoBoundary***$((A, B), D, T)$: When a moving entity A is *NTPP* to a reference entity B, and A is moving to the boundary of B over a time interval T. For all $t \in T$, $NTPP(A, B)$ holds and the relative distance D is decreasing inside B over T :

    $$MovetoBoundary((A, B), D, T) \equiv Holds(NTPP(A, B), d_{int-}, T)$$



  - ***AroundInside***$((A, B), D, T)$: When a moving entity A is *NTPP* to a reference entity B, and A is either moving around the boundary of B or static relative to B over a time interval T. For all $t \in T$, $NTPP(A, B)$ holds and the relative distance D is constant inside B over T :

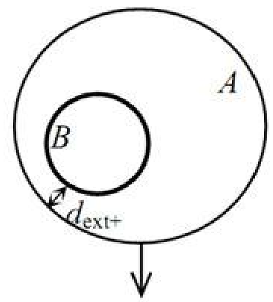
    $$AroundInside((A, B), D, T) \equiv Holds(NTPP(A, B), d_{int-}, T)$$



Classification of movement

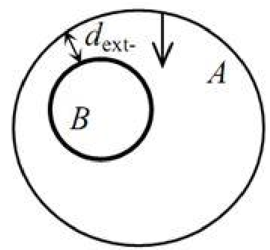
- Movement inside a reference entity
  - ***EmbracingMoveOutside***$((A, B), D, T)$: When a moving entity A is *NTPPI* to a reference entity B, and A is moving outside B over a time interval T. For all $t \in T$, $NTPPI(A, B)$ holds and the relative distance relationship D is increasing outside B over T :

$EmbracingMoveOutside((A, B), D, T) \equiv Holds(NTPPI(A, B), d_{ext+}, T)$



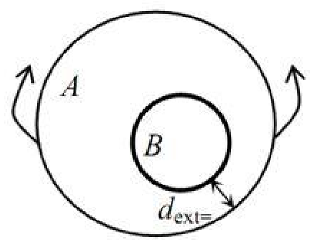
  - ***EmbracingMovetoBoundary***$((A, B), D, T)$: When a moving entity A is *NTPPI* to a reference entity B, and A is moving to the boundary of B over a time interval T. For all $t \in T$, $NTPPI(A, B)$ holds and the relative distance D is decreasing outside B over T :

$EmbracingMovetoBoundary((A, B), D, T) \equiv Holds(NTPPI(A, B), d_{ext-}, T)$



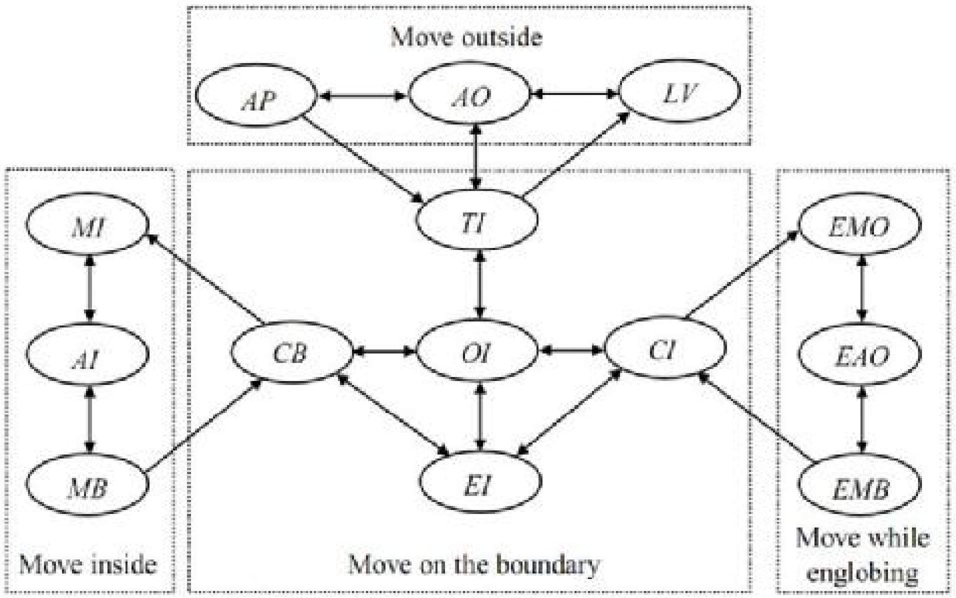
  - ***EmbracingAroundOutside***$((A, B), D, T)$: When a moving entity A is *NTPPI* to a reference entity B, and A is either moving around or static outside of B over a time interval T. For all $t \in T$, $NTPPI(A, B)$ holds and the relative distance D is constant outside B over T :

$EmbracingAroundOutside((A, B), D, T) \equiv Holds(NTPPI(A, B), d_{ext-}, T)$



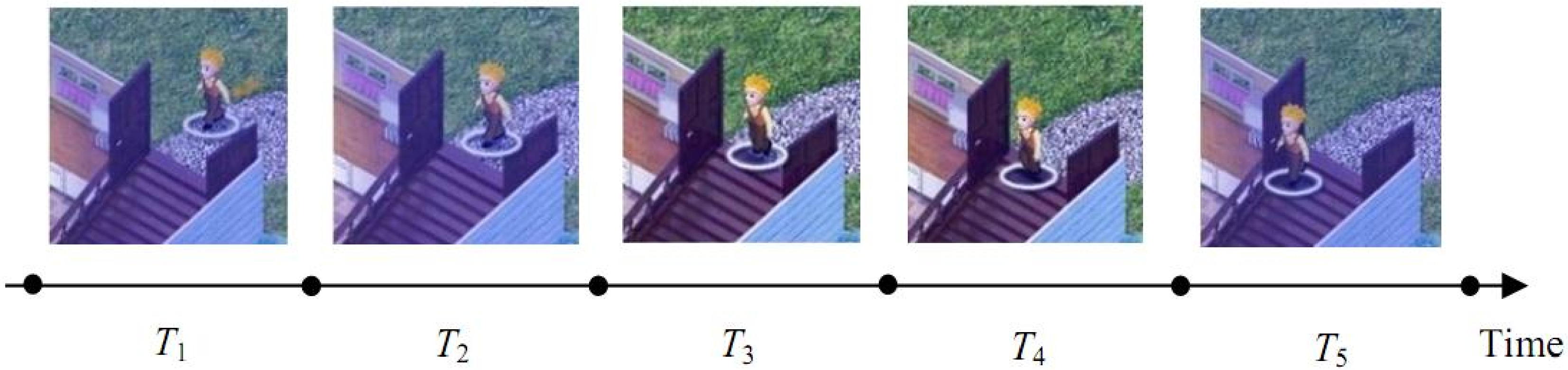
Conceptual neighbor diagram

- Conceptual neighbors provide additional reasoning capabilities to **anticipate future movements** and to **develop reasoning mechanisms** in case of incomplete knowledge.
  - Two movements are conceptual neighbors, if there is a **continuous transition** between them **without any intermediary movement**.
  - A **bidirectional arrow** indicates that the relationships on each side can be directly transformed into the other by a continuously transition.
  - A **one-way arrow** shows the direction of the transition.



Case study 1: a sequence of human movements

- *Enter*((*A*, *B*), *T*): A man *A* enters a room *B* over a time interval *T*. With T_1, T_2, T_3, T_4, T_5 and $T_1 < T_2 < T_3 < T_4 < T_5$, then this sequence of movements is defined as:
  - $Enter((A, B), T) \equiv events(Approach((A, B), D_1, T_1) \wedge Touching((A, B), D_2, T_2) \wedge Overlapping((A, B), D_3, T_3) \wedge CoveringBy((A, B), D_4, T_4) \wedge MovetoInterior((A, B), D_5, T_5))$



Movements of a man that enters a room

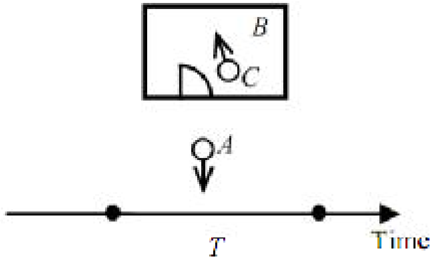
Case study 2: movements between two men and a room

- The man *A* is leaving the room *B* and the man *C* is moving to the interior of the room *B* over the time interval *T*.
  - *We have:*

    $Leave((A, B), D, T) \equiv Holds(DC(A, B), d_{ext+}, T)$,

    $MovetoInterior((C, B), D, T) \equiv Holds(NTPP(C, B), d_{int+}, T)$
  - The result of the composition of these movement configuration

    $Leave((A, C), D, T) \equiv Holds(DC(A, C), d_{ext+}, T)$



Composition table between two men and a room

	LV	AO	AP	TI	OI	CI	MI	AI	MB
LV	LV, AP, TI	LV, AP, TI	LV, AP, TI	LV	LV	LV	LV	LV	LV
AO	LV, AP, TI	LV, AP, TI	LV, AP, TI	LV, AP, AO	LV, AP, AO	LV, AP	LV, AP	LV, AP	LV, AP
AP	LV, AP, TI	LV, AP, TI	LV, AP, TI	AP	AP	AP	LV, AP	LV, AP	LV, AP
TI	LV	LV, AP, AO	AP	LV, AP, TI	LV, AP, TI	LV, AP, TI	LV, AP	LV, AP	LV, AP
OI	LV	LV, AP, AO	AP	LV, AP, TI	LV, AP, TI	LV, AP, TI	LV, AP	LV, AP	LV, AP
CI	LV	LV, AP	AP	LV, AP, TI	LV, AP, TI	LV, AP, TI	LV, AP	LV, AP, TI	LV, AP, TI
MI	LV	LV, AP	LV, AP	LV, AP	LV, AP	LV, AP	LV, AP, TI	LV, AP, TI	LV, AP, TI
AI	LV	LV, AP	LV, AP	LV, AP	LV, AP	LV, AP, TI	LV, AP, TI	LV, AP, TI	LV, AP, TI
MB	LV	LV, AP	LV, AP	LV, AP	LV, AP	LV, AP, TI	LV, AP, TI	LV, AP, TI	LV, AP, TI

Conclusion

- The proposed model is based on two complementary qualitative primitives :
  - ***RCC*8 algebra**
  - **Qualitative distances**
- The framework developed favors the identification of a series of movement primitives that qualify the **relative movements** of two evolving entities, as well as **movement transitions**.
- Further work
  - Study the **sequences of movement** and **patterns** that emerge from a group of moving objects.
  - **Validate the model** by prototype developments applied to human and robot navigations in indoor spaces.
  - **Cognitive evaluation** of the primitive evaluations and linguistic terms identified

Thank you very much for

your attention !

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