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CIS 700
2017

Simulating Heterogeneous Crowds

Based on a Eurographics 2014 Tutorial

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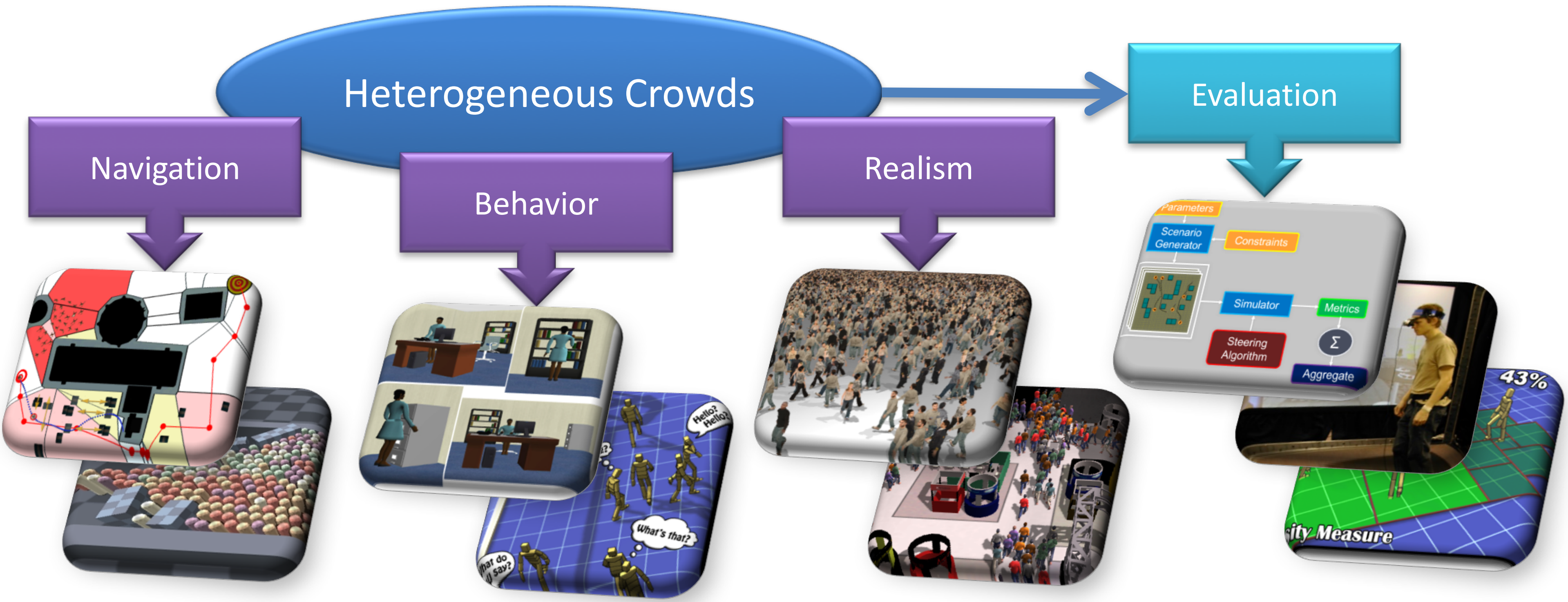
Overview


Heterogeneous Crowds
Evaluation
Navigation
Behavior
Realism
Hello? Hello?
What's that?
Parameters
Scenario Generator
Constraints
Simulator
Metrics
Steering Algorithm
Σ
Aggregate
43%

Simulating Heterogeneous Crowds

NAVIGATION

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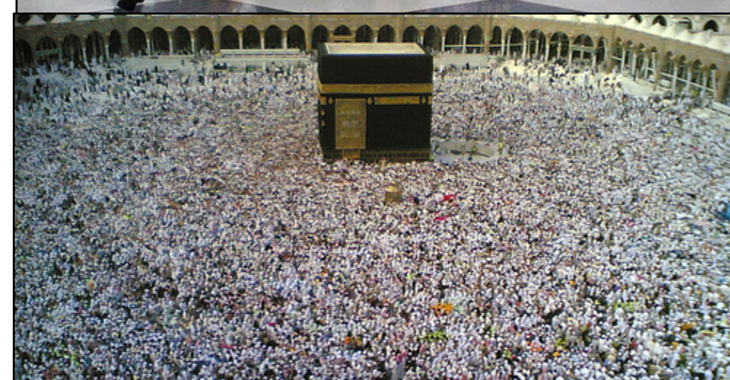
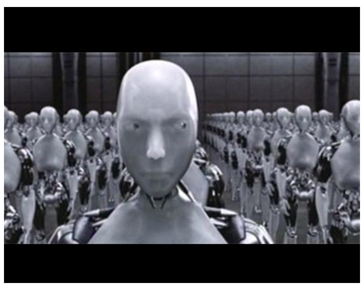
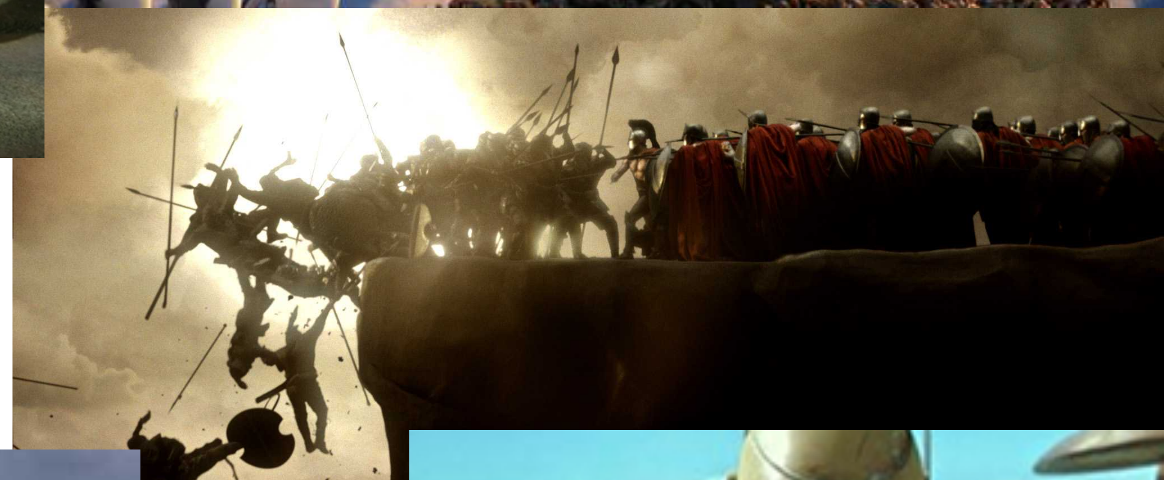
Crowd Simulation Challenges

- People navigate in very difficult circumstances
  - Complex environments
  - Fast paced motion
  - Very dense crowds

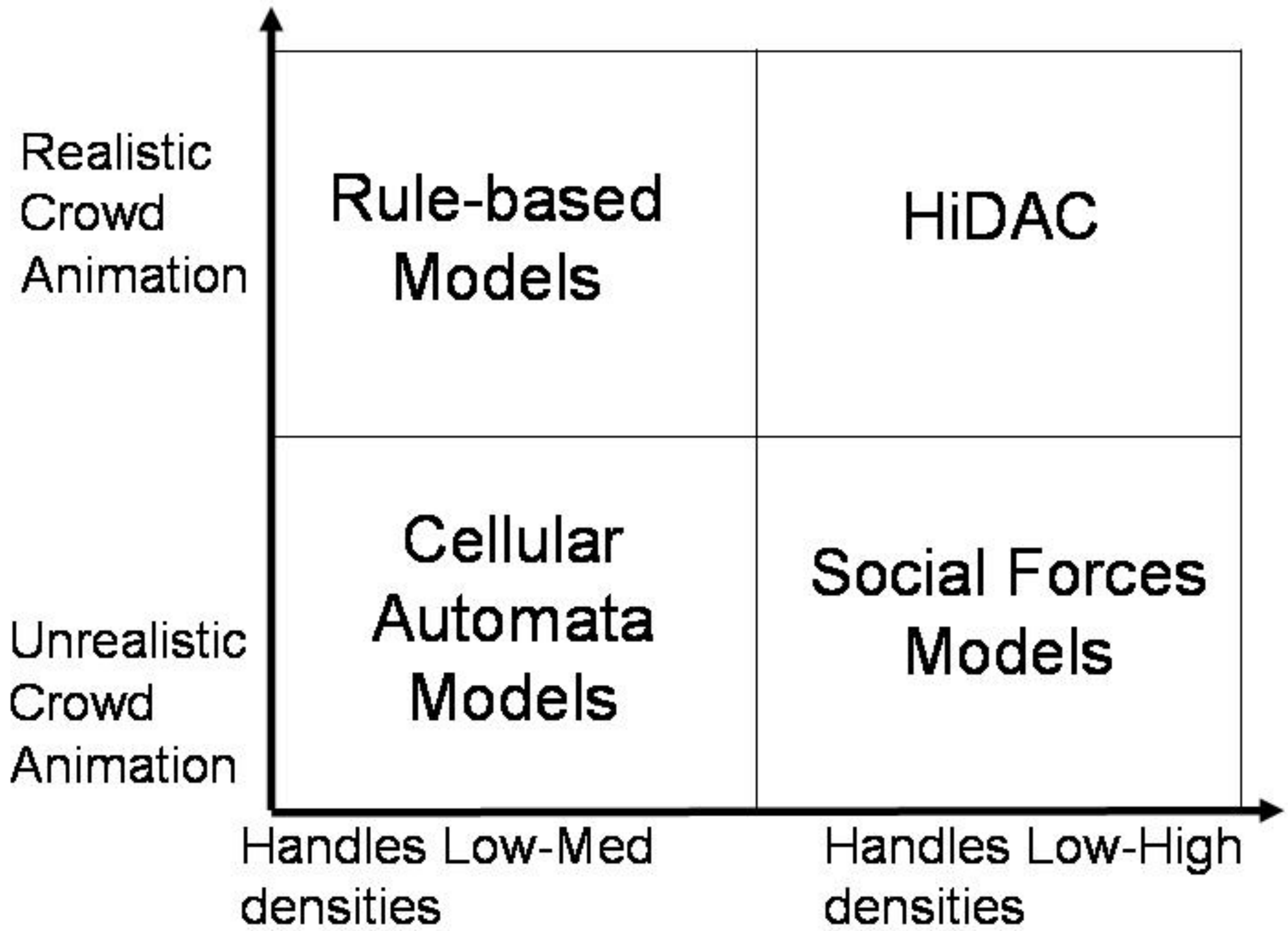


How can we *reproduce* this ability in virtual environments?



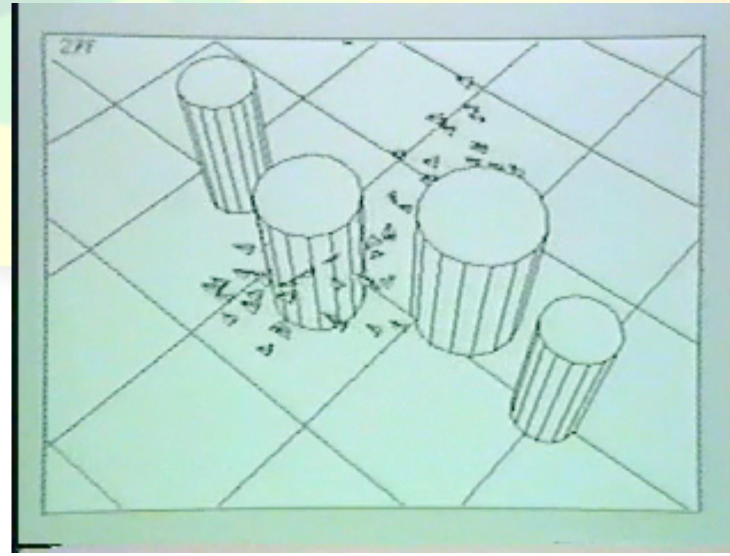


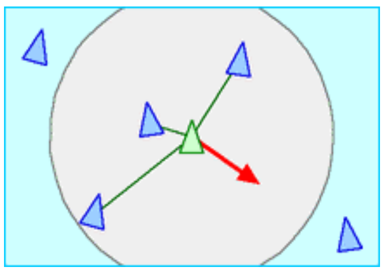
Approaches to Crowd Animation

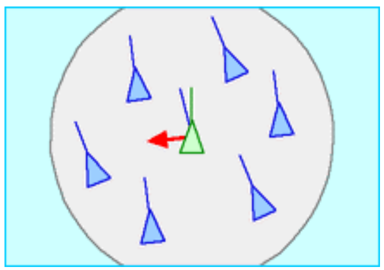


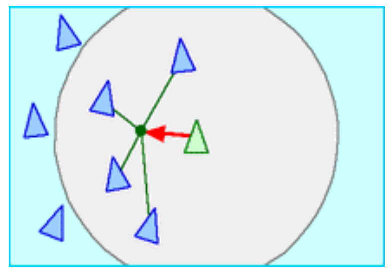
Rules: Simulating Flocks & Herds

- Boids Algorithm [Reynolds ‘87]
  - Three simple rules, applied to each timestep, in a local neighborhood:

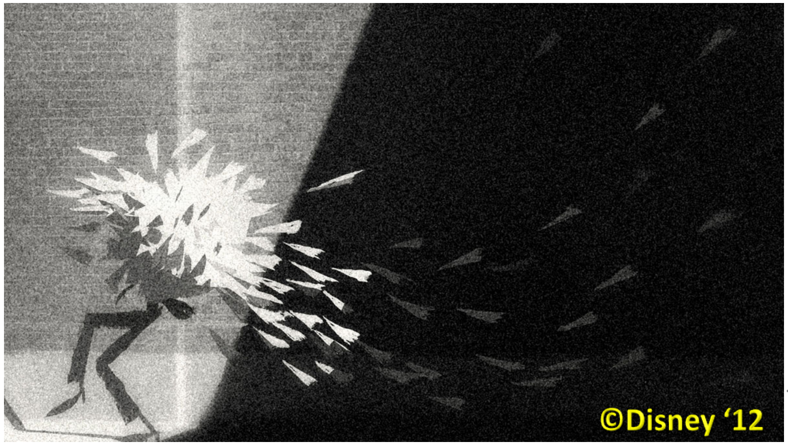



Separation


Alignment


Cohesion

- Commonly used for CGI animals:



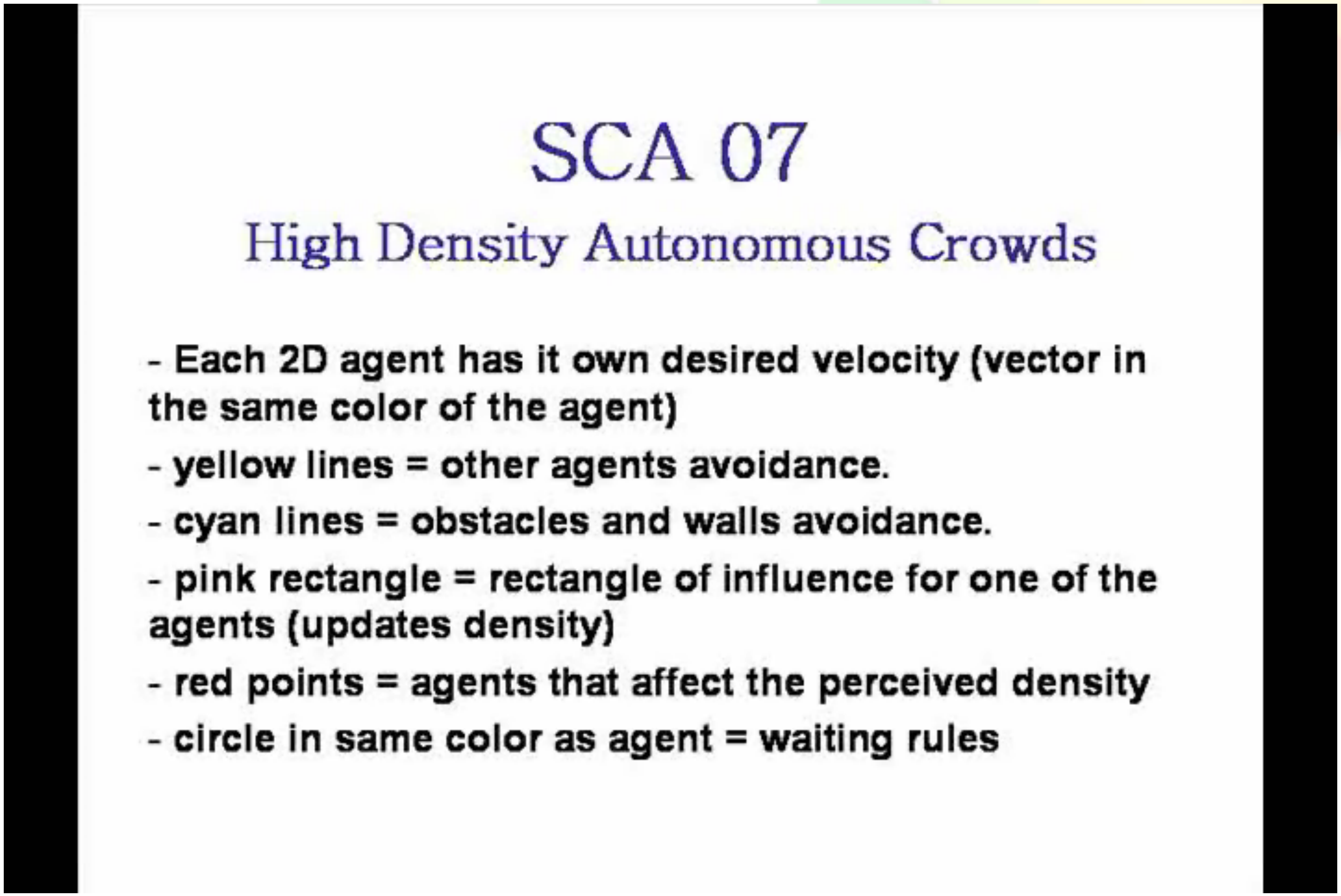
The HiDAC Model: Forces plus Geometry (Pelechano, Allbeck, Badler, SCA 2007)

- Forces influencing the direction of movement (for the i^{th} agent at the n^{th} time step):

$$\mathbf{F}_i^{To}[n] = \underbrace{\mathbf{F}_i^{To}[n-1]}_{\text{Current direction}} + \underbrace{\mathbf{F}_i^{At}[n] w_i^{At}}_{\text{Attractor}} + \underbrace{\sum_{w} \mathbf{F}_{wi}^{Wa}[n] w_i^{Wa}}_{\text{Walls}} + \underbrace{\sum_{k} \mathbf{F}_{ki}^{Ob}[n] w_i^{Ob}}_{\text{Obstacles}} + \underbrace{\sum_{j(\neq i)} \mathbf{F}_{ji}^{Ot}[n] w_i^{Ot}}_{\text{Other Agents}}$$

- Forces used to compute new agent position at time n+1.

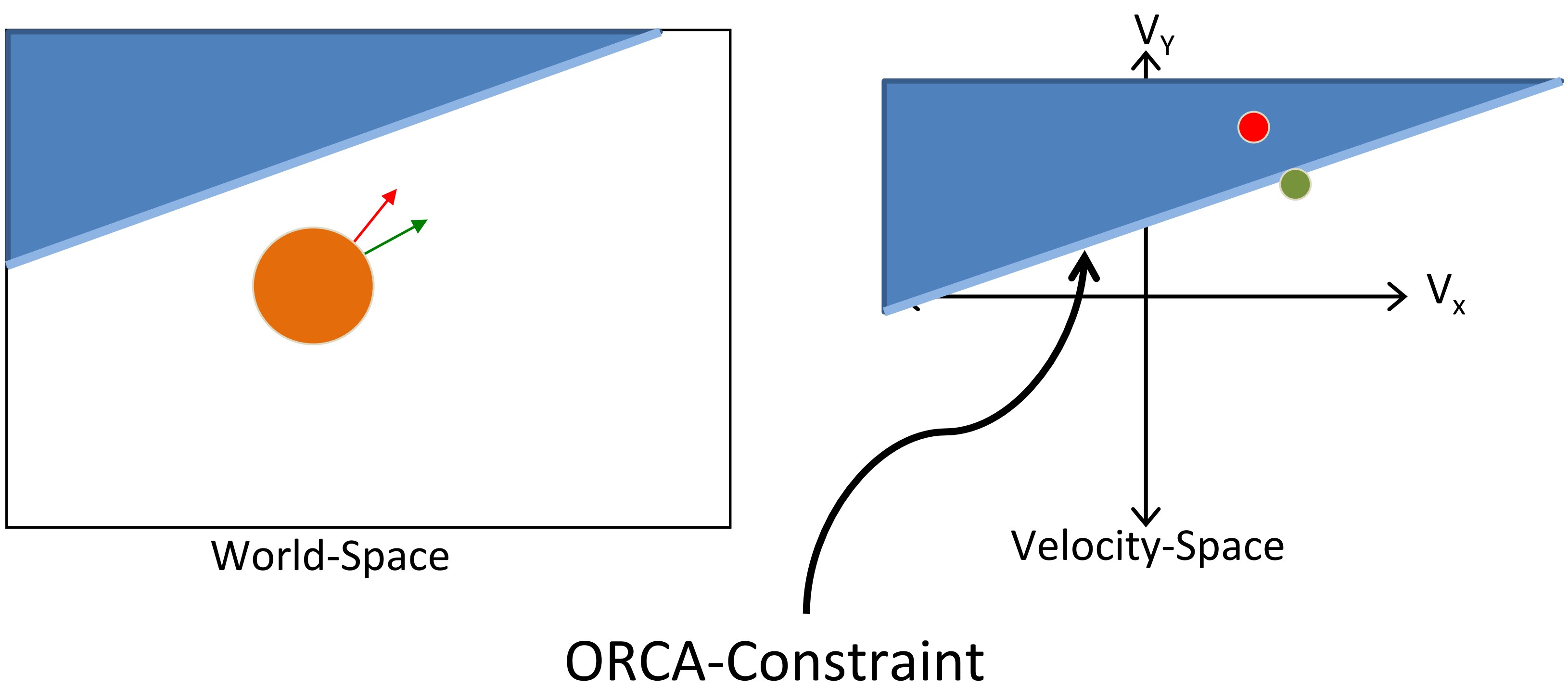
HiDac Animations



Optimal Reciprocal Collision Avoidance (ORCA)

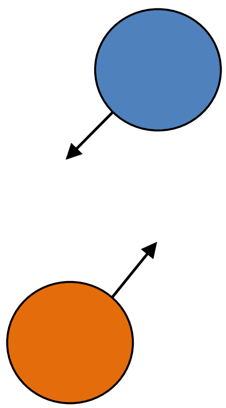
(J. van den Berg, S. J. Guy, M. Lin, D. Manocha, STAR 2011)

- Identify the set of agent velocities which might collide soon, and then avoid them!
- Key Idea: These velocities can be found geometrically, followed by an optimization step.



Agent-Agent Interactions

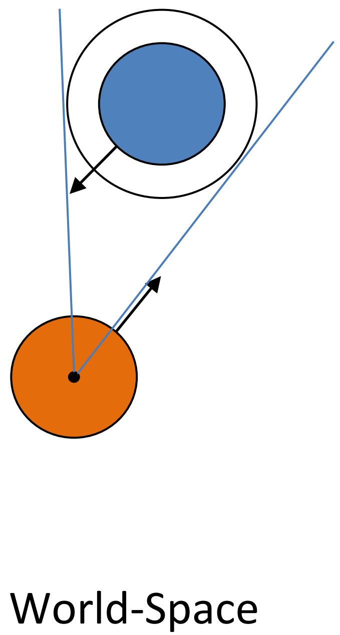
- Linear velocity constraints can be formulated for agent pairs
  - Key Idea: Reciprocity – Each agent must avoid at least ½ the collision.

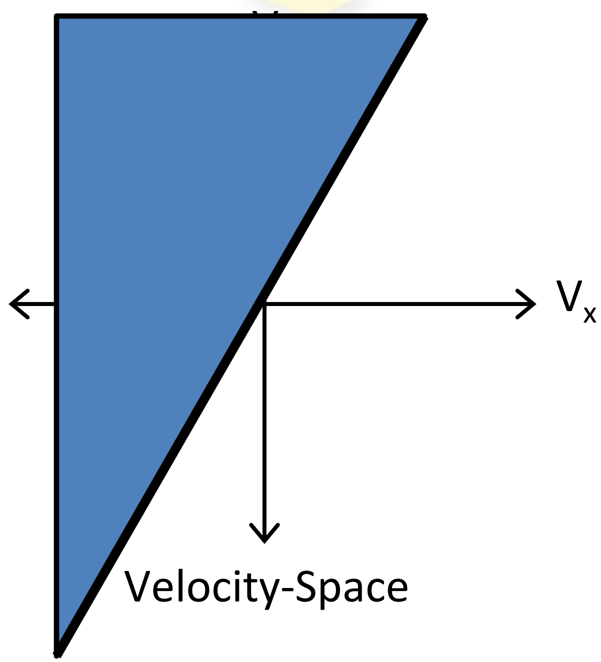


World-Space

Agent-Agent Interactions

- Linear velocity constraints can be formulated for agent pairs
  - So expand radius of other agent by “my” radius (Minkowski sum of agent outlines).



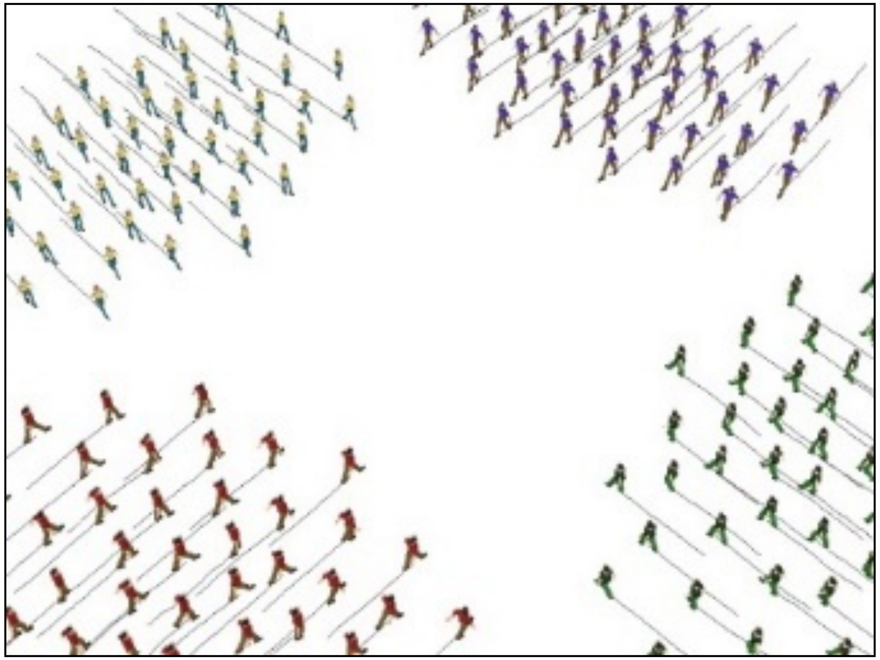


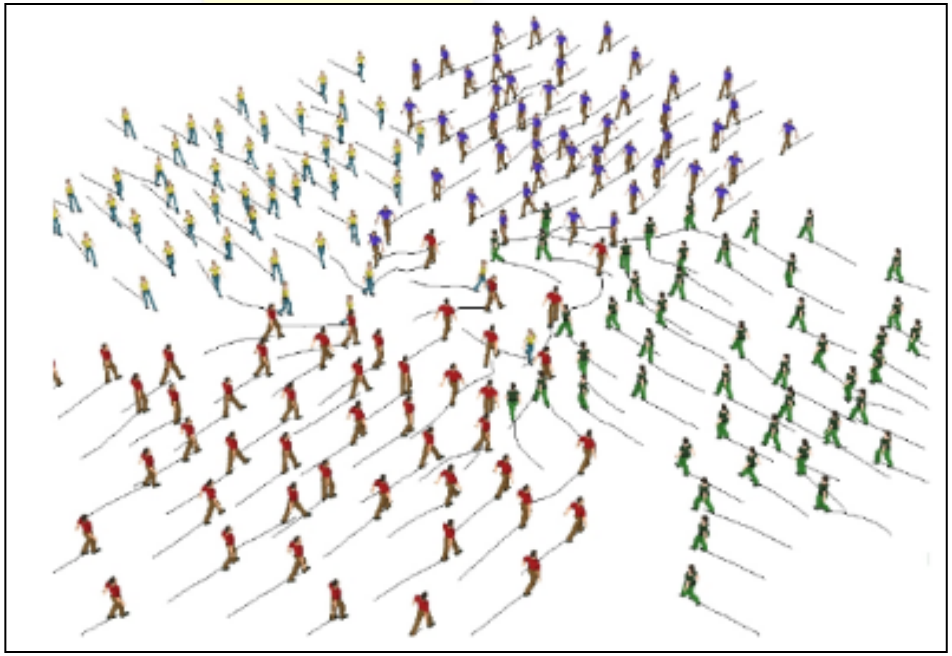
- https://www.youtube.com/watch?v=Hc6kng5A8lQ

Continuum Crowds
(Treuille and Popović, SIGGRAPH 2006)

BioCrowds (Soraia Musse)

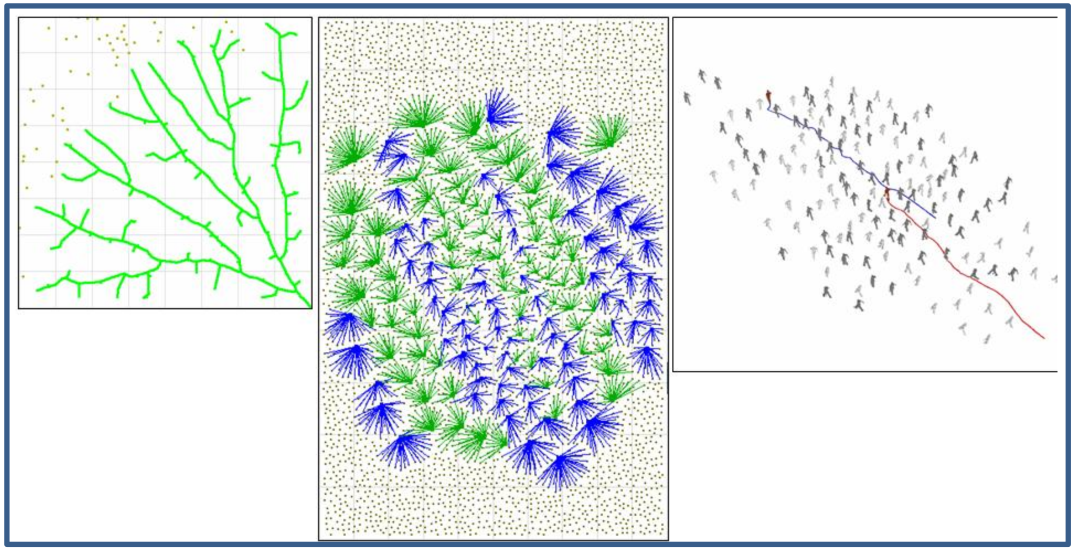
- Crowd simulation based on biological patterns.



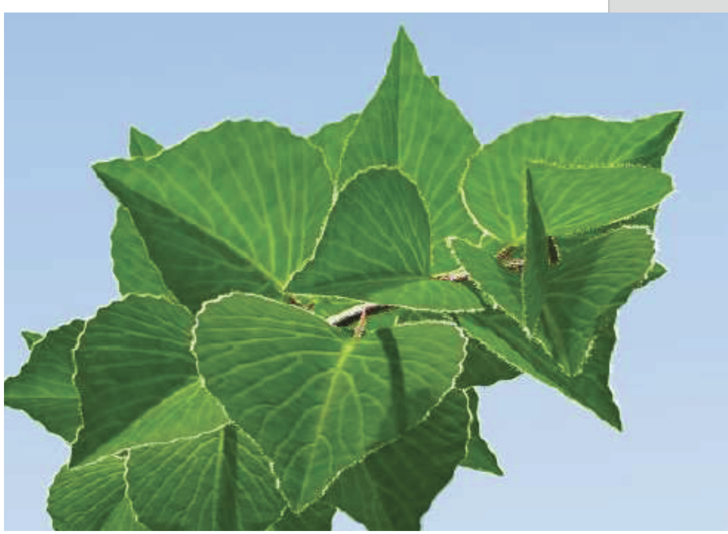


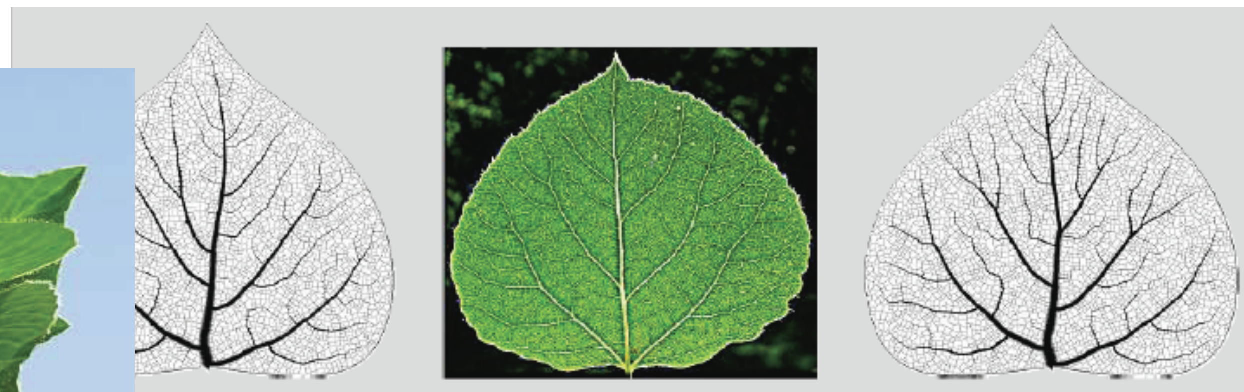
BioCrowds

- doi:10.1016/j.cag.2011.12.004 (Bicho et al, CG&A, 2012)
- A method for crowd simulation based on a biologically motivated space colonization algorithm which was originally introduced to model leaf venation patterns and the branching architecture of trees
- BioCrowds operates by simulating the competition for space between agents



Results (Runions' method)





A. Runions, M. Fuhrer, B. Lane, P. Federl, A.-G. Rolland-Lagan, P. Prusinkiewicz
Modeling and visualization of leaf venation patterns. ACM Trans Graph, 24 (3) (2005), pp. 702–711

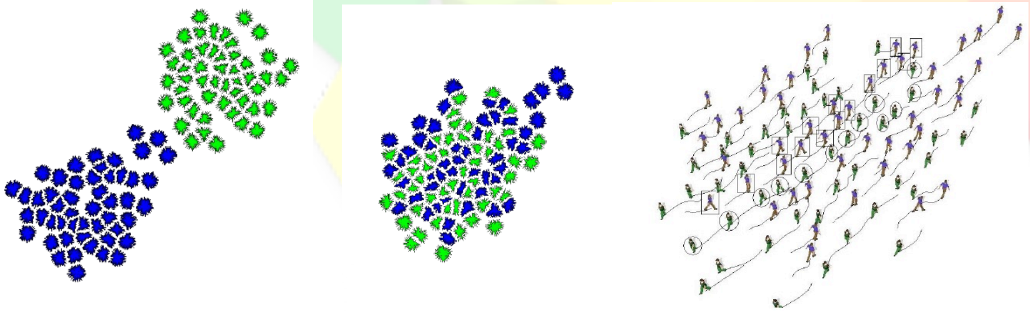
BioCrowds

- Parameters:
  - *N Markers (Dart-throwing);*
  - *Agent i positions* x_i*(t), goals* g_i*(t) and desired maximum speed* s_{max}^i
  - Perception field (Circular region) R_i.
- At each timestep and for a given agent i:
  - $A = \{a_1, a_2, \dots, a_N\}$, markers that are closer to agent i than any other agent
  - $m = \sum_{k=1}^{N} w_k(a_k - x)$, motion vector
  - $w_k = \frac{f(g-x, a_k-x)}{\sum_{i=1}^{N} f(g-x, a_i-x)}$, f should prioritize markers that lead the agent directly to its goal
  - $v = s\frac{m}{\|m\|}$, where $s = \min\{\|m\|, s_{max}\}$, v is agent displacement
  - Next agent position is $x(t+1) = x(t) + v$

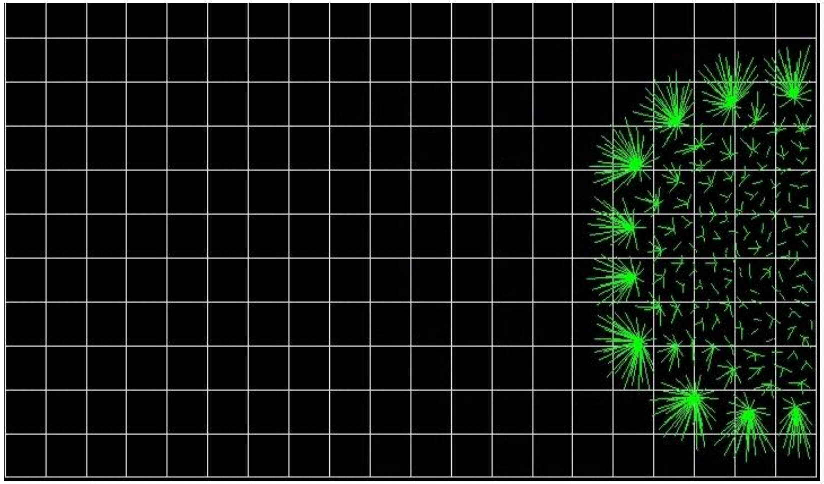
- See https://www.youtube.com/watch?v=jqfeds_VqNg

BioCrowds: Examples of Emergent Behaviors

- Lanes formation:



- Arc formation:

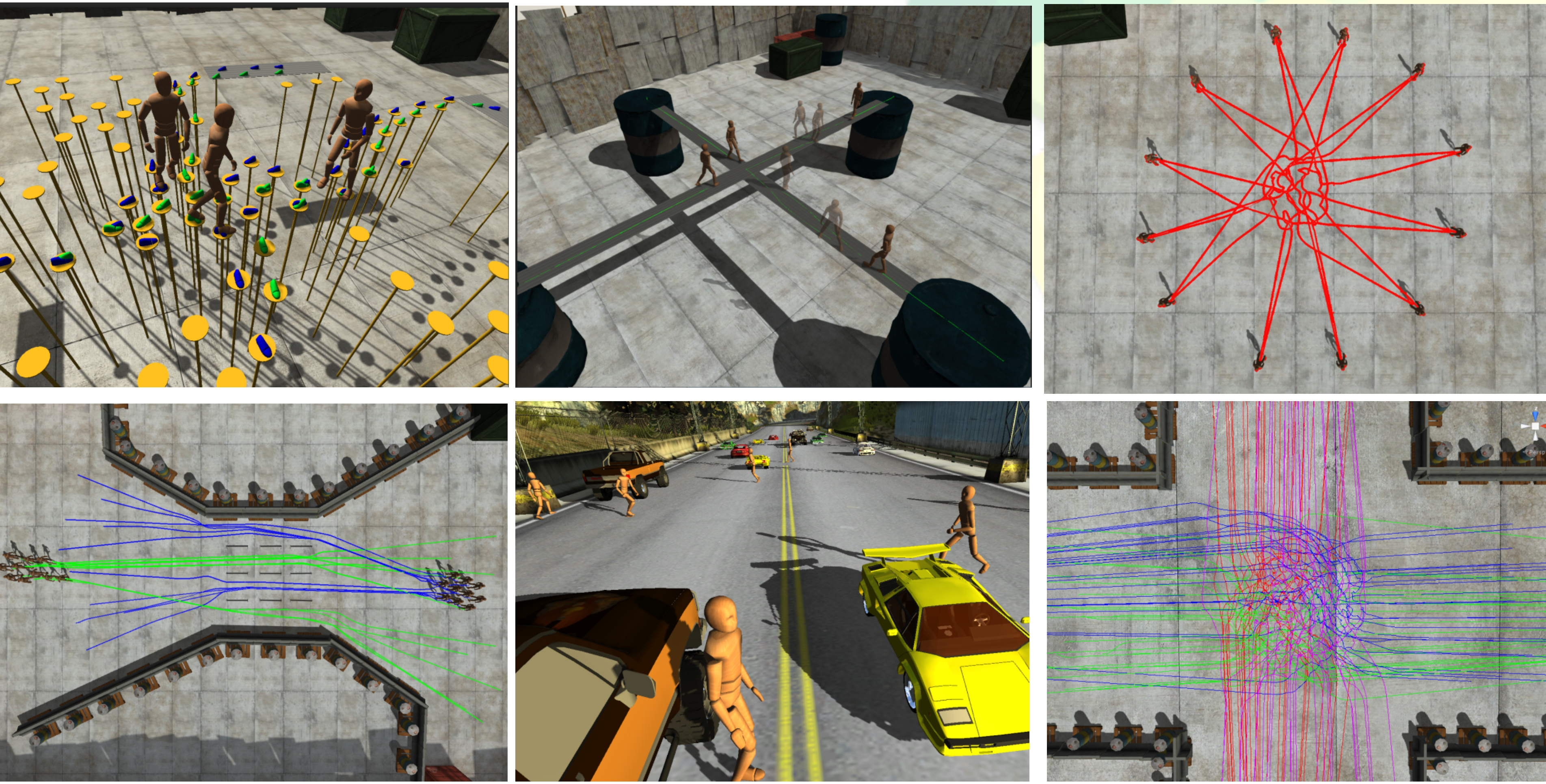


- Integrate with environment: https://www.youtube.com/watch?v=EP4RSGR4Mh0

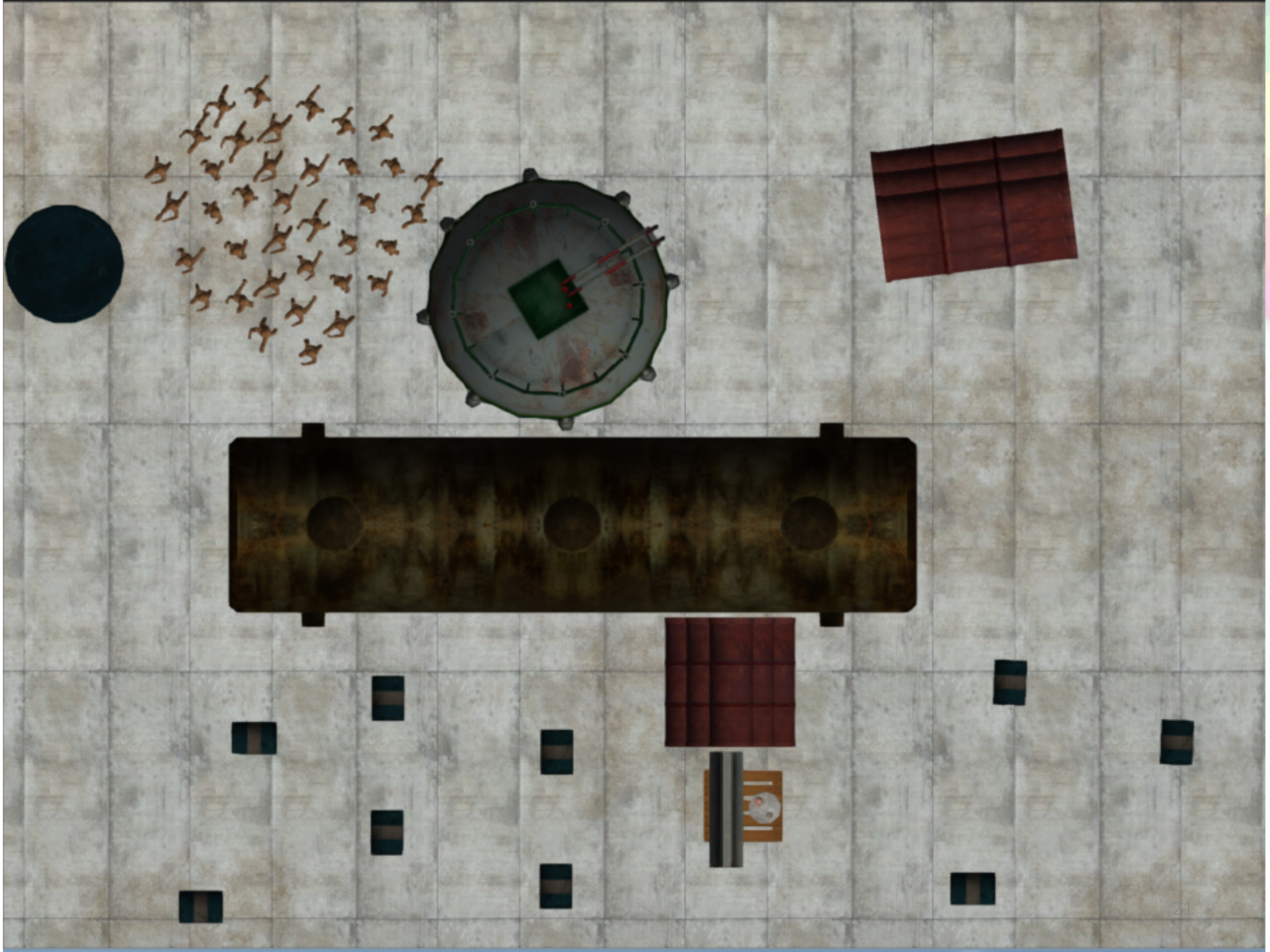
BioCrowds: Problems

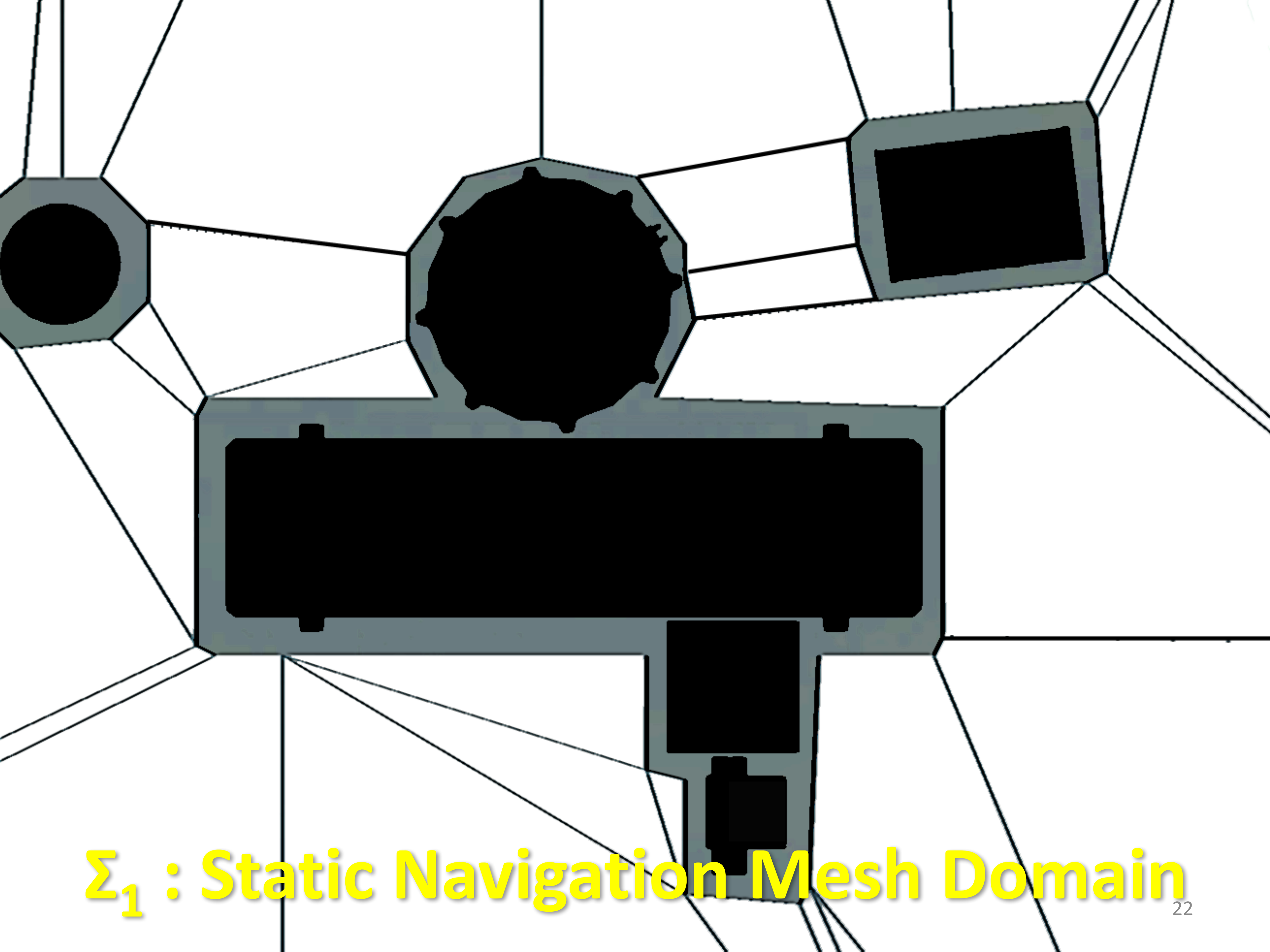
- An agent does not see any other
- Local minimum traps (there was no path planning)

Need for high fidelity navigation in complex, dynamic virtual environments

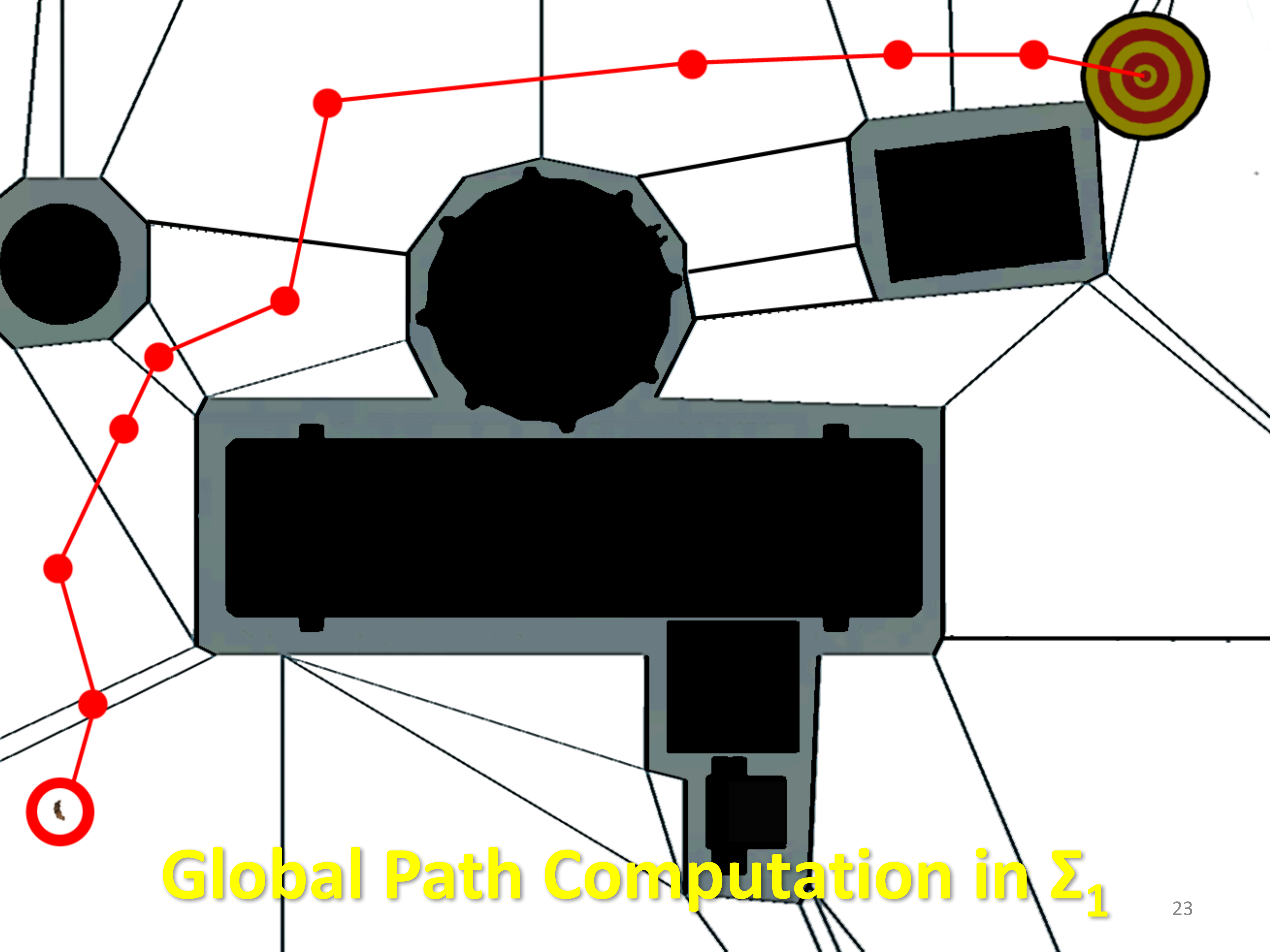


Real-time system that can handle many characters, without compromising control fidelity.

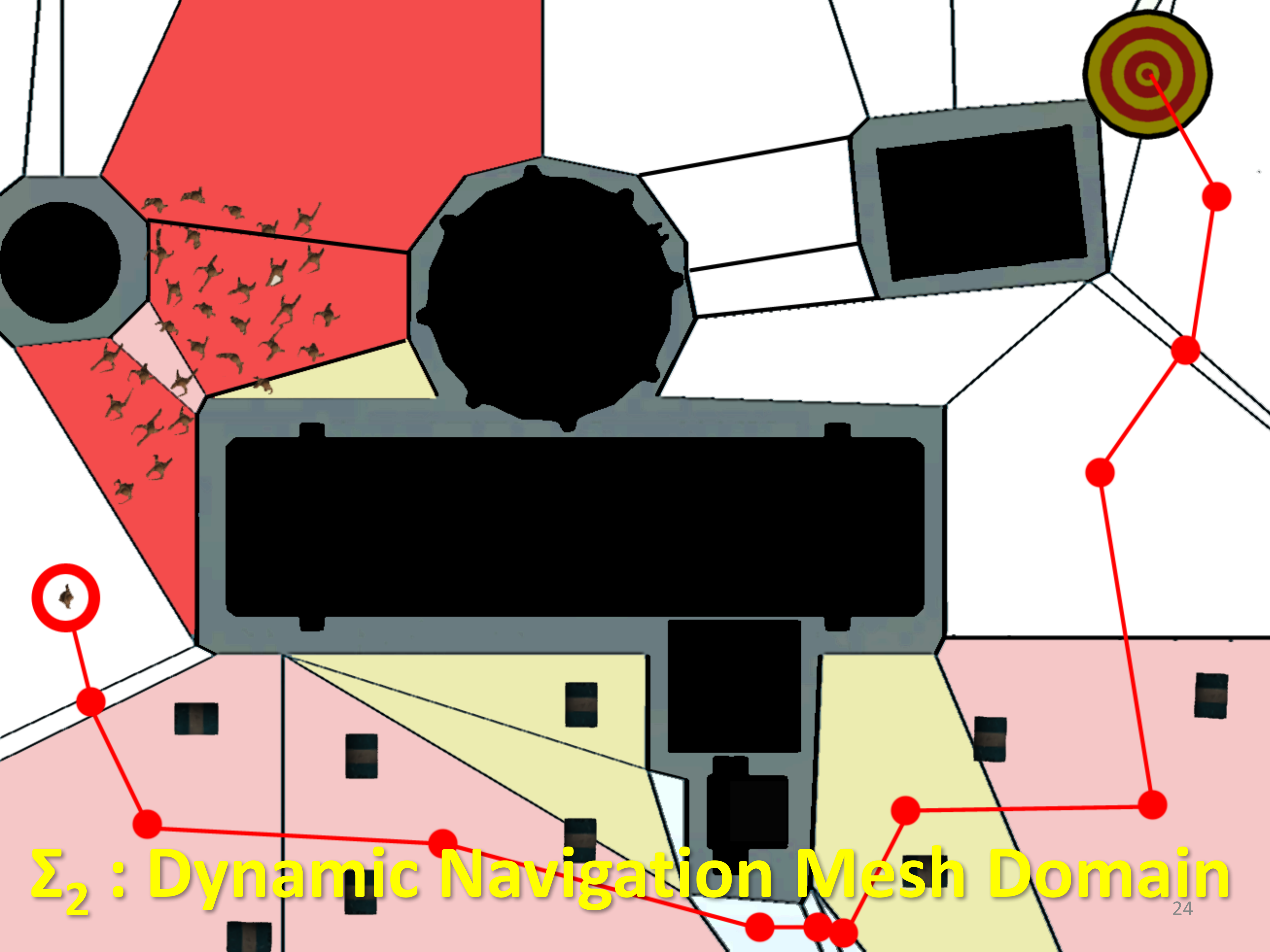




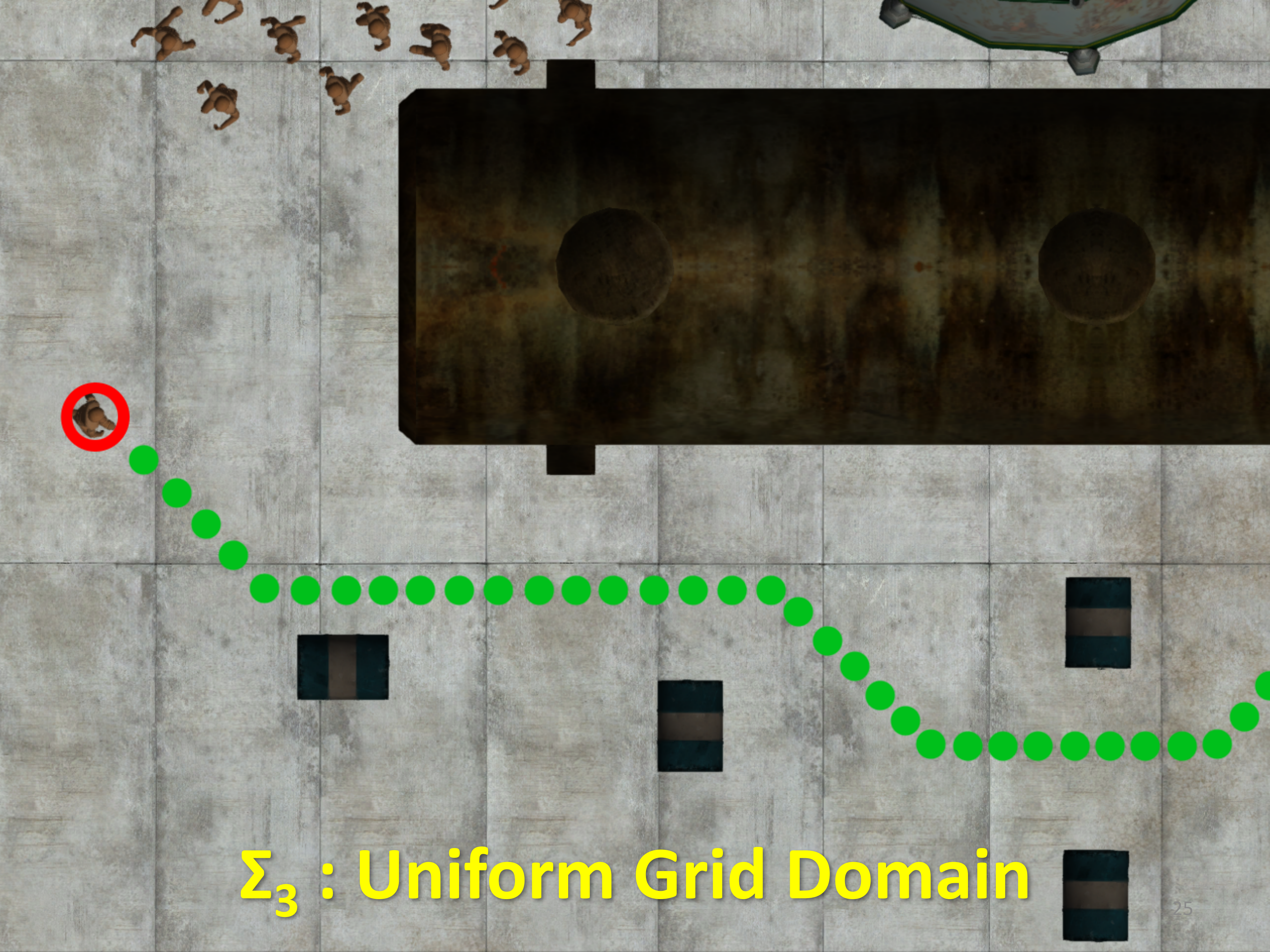
Σ_1 : Static Navigation Mesh Domain



Global Path Computation in Σ_1



Σ_2 : Dynamic Navigation Mesh Domain


Σ_3 : Uniform Grid Domain


Σ_4 : Space-Time Domain

Footstep Level Navigation Planning

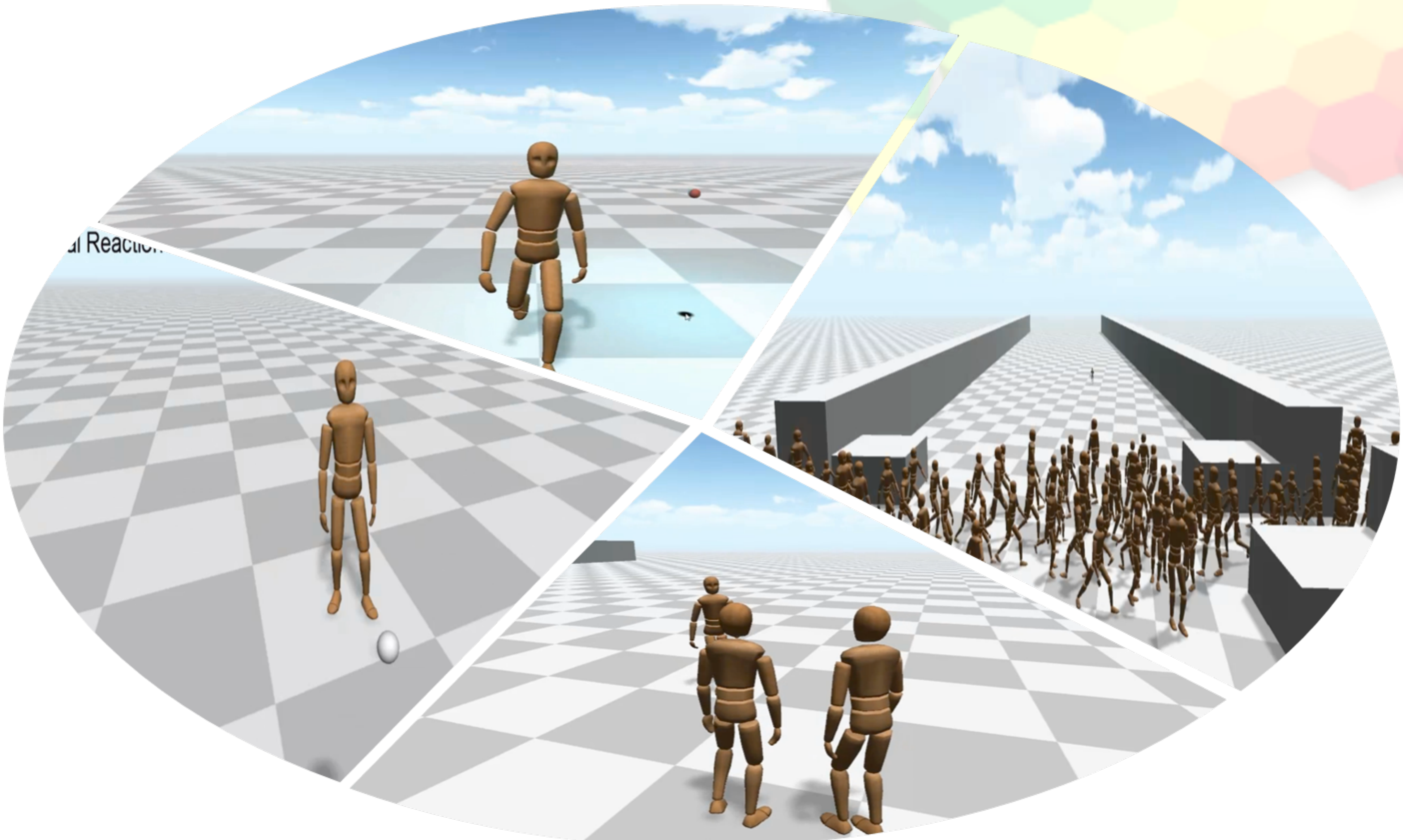
Multi-Domain Planning (example)

Path Constraints and Relations

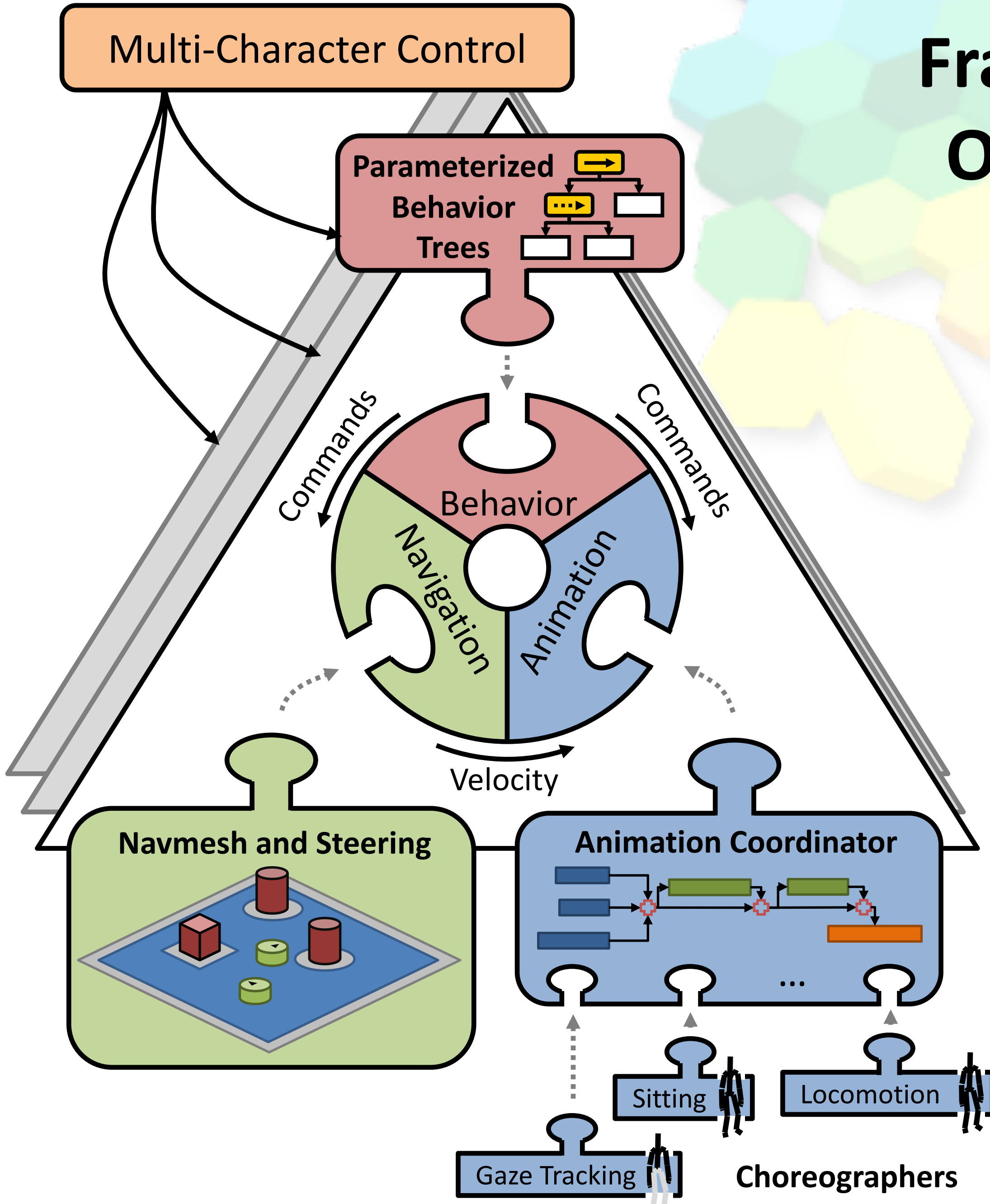
Behavior

ADAPT: The Agent Development and Prototyping Testbed

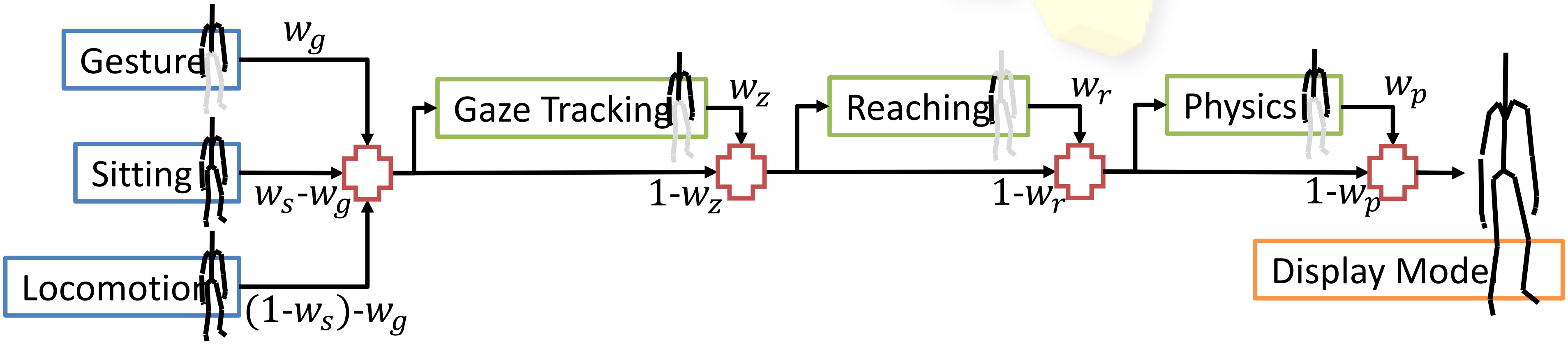
Mubbasir Kapadia
Disney Research, Zurich



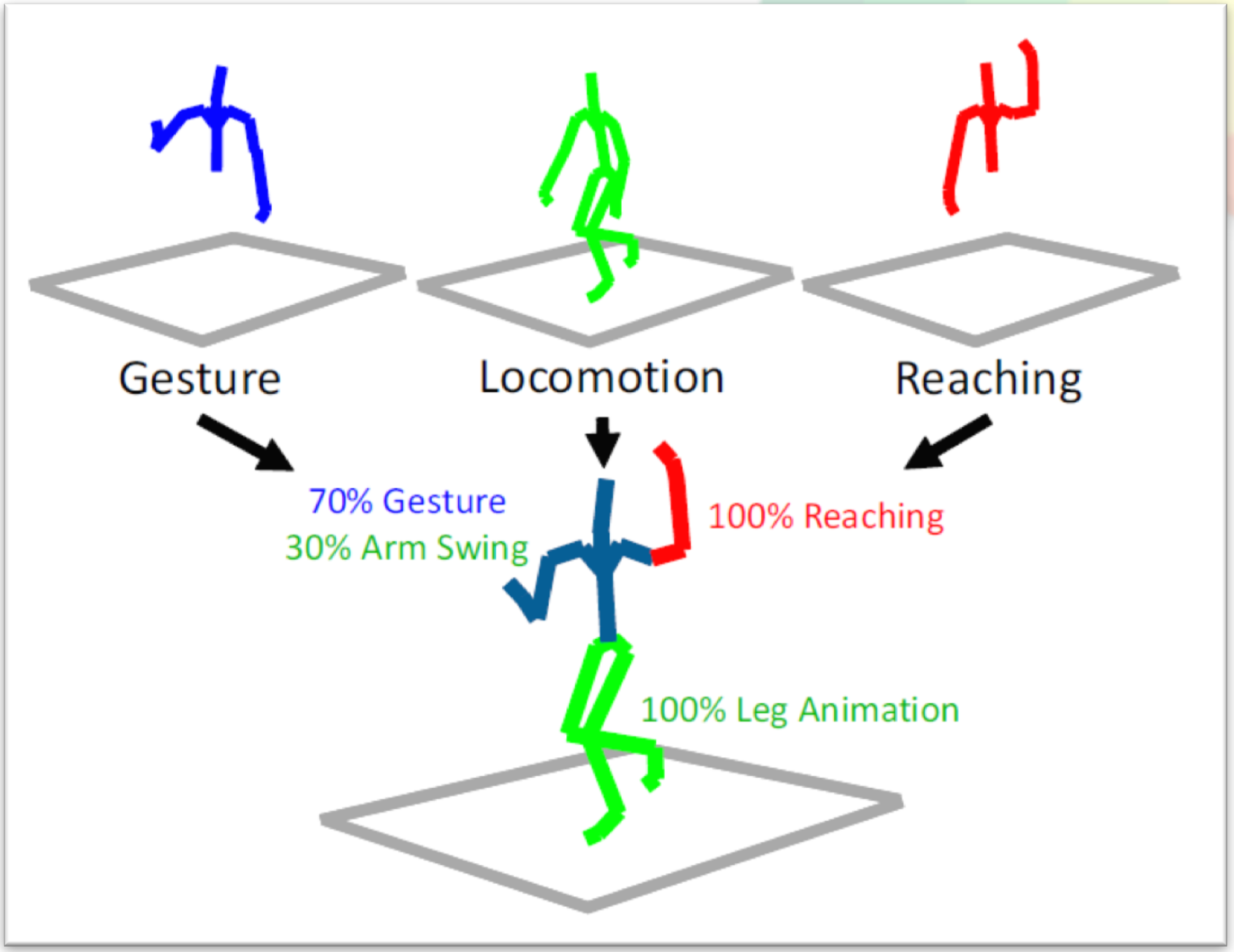
Framework Overview

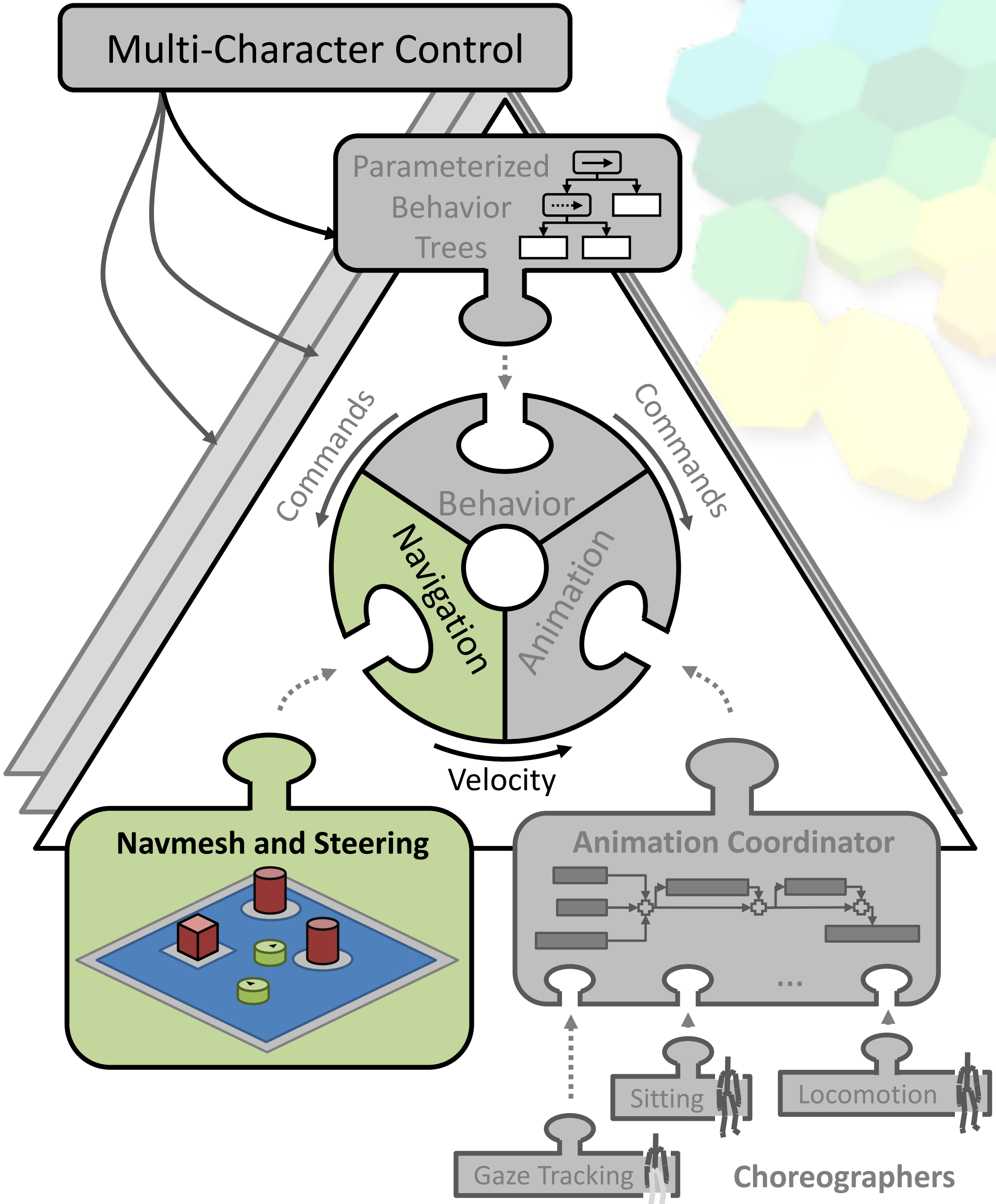


Choreographer Data-flow Diagram

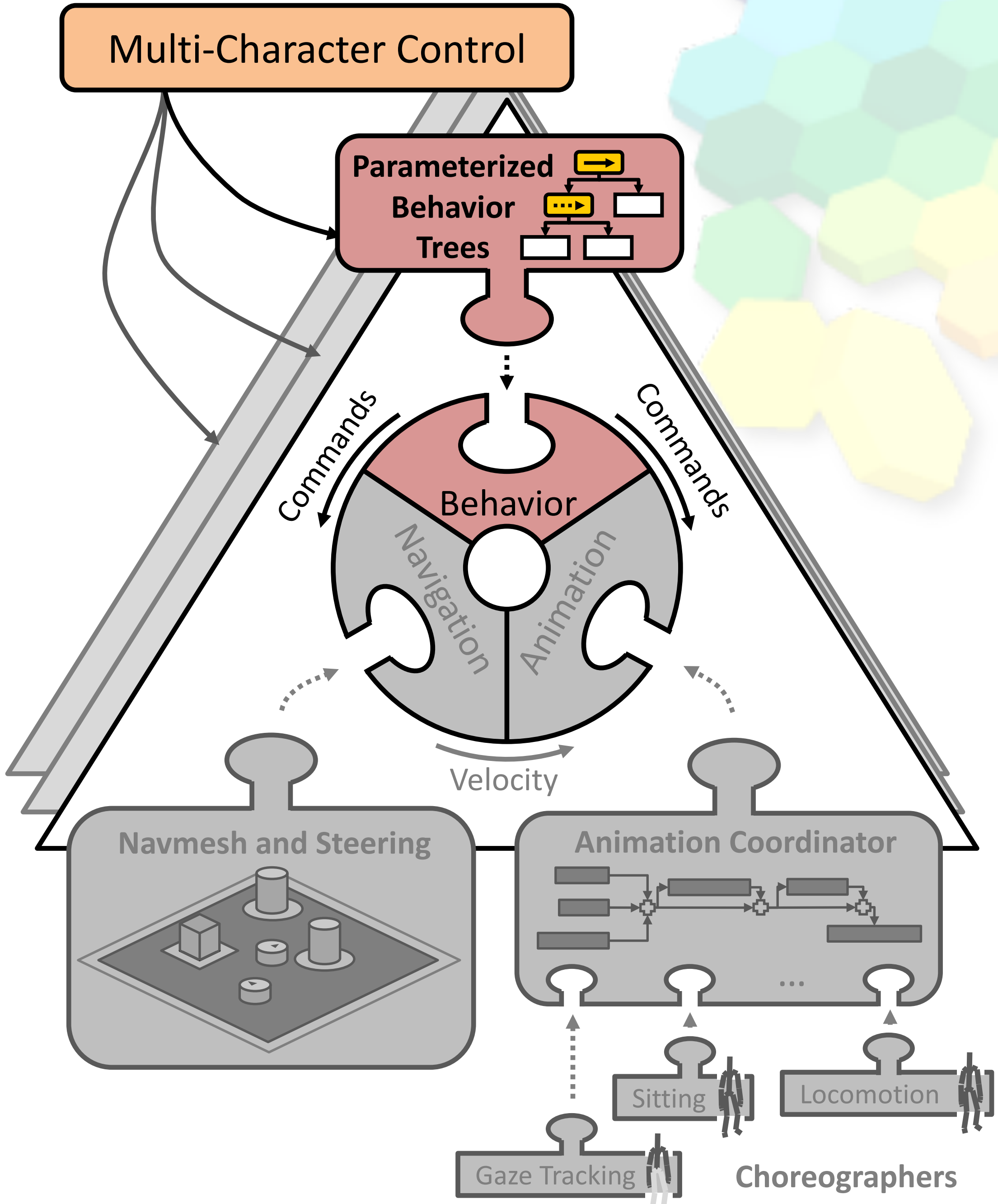


Shadow Blending





Multi-Character Control
Parameterized
Behavior
Trees
Commands
Commands
Behavior
Navigation
Animation
Velocity
Navmesh and Steering
Animation Coordinator
...
Sitting
Locomotion
Gaze Tracking
Choreographers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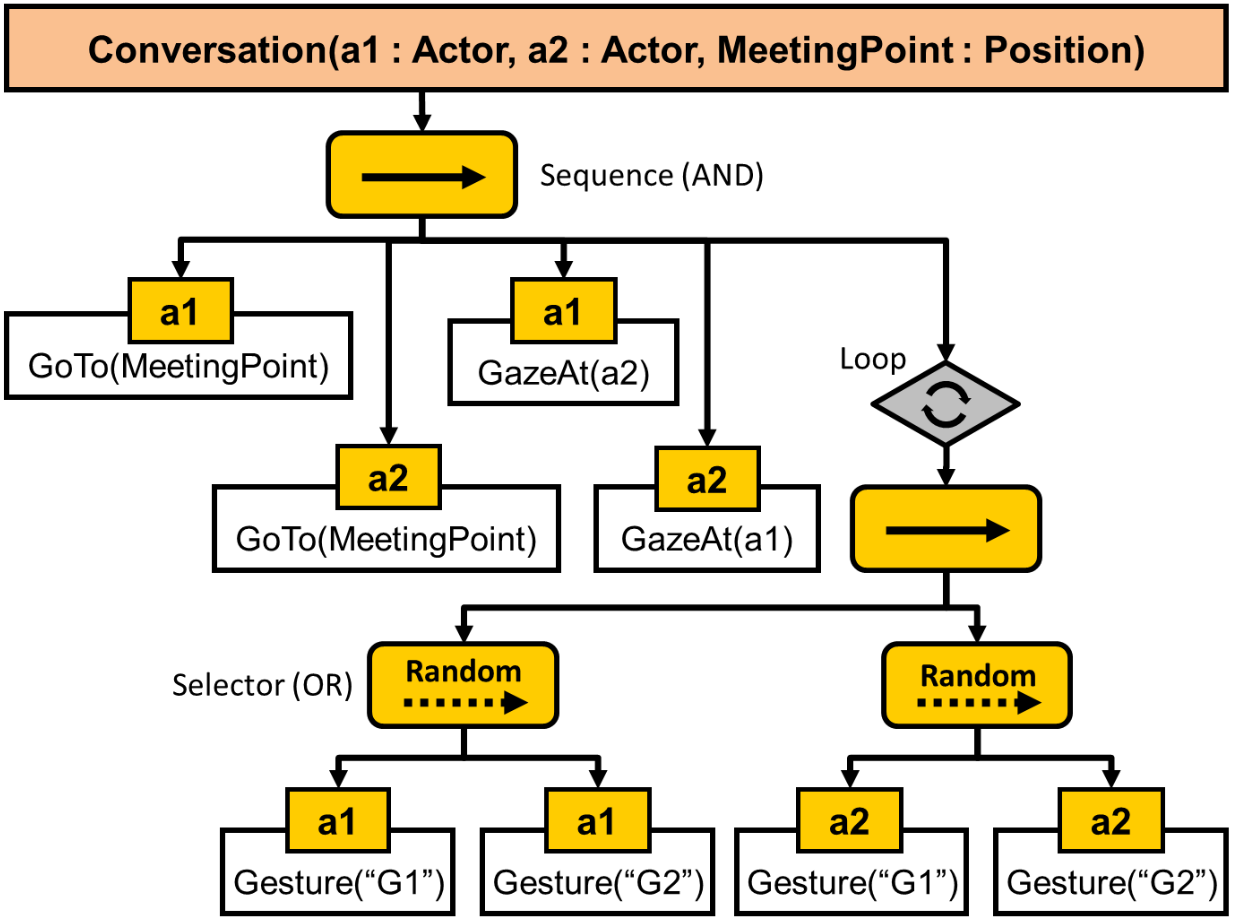
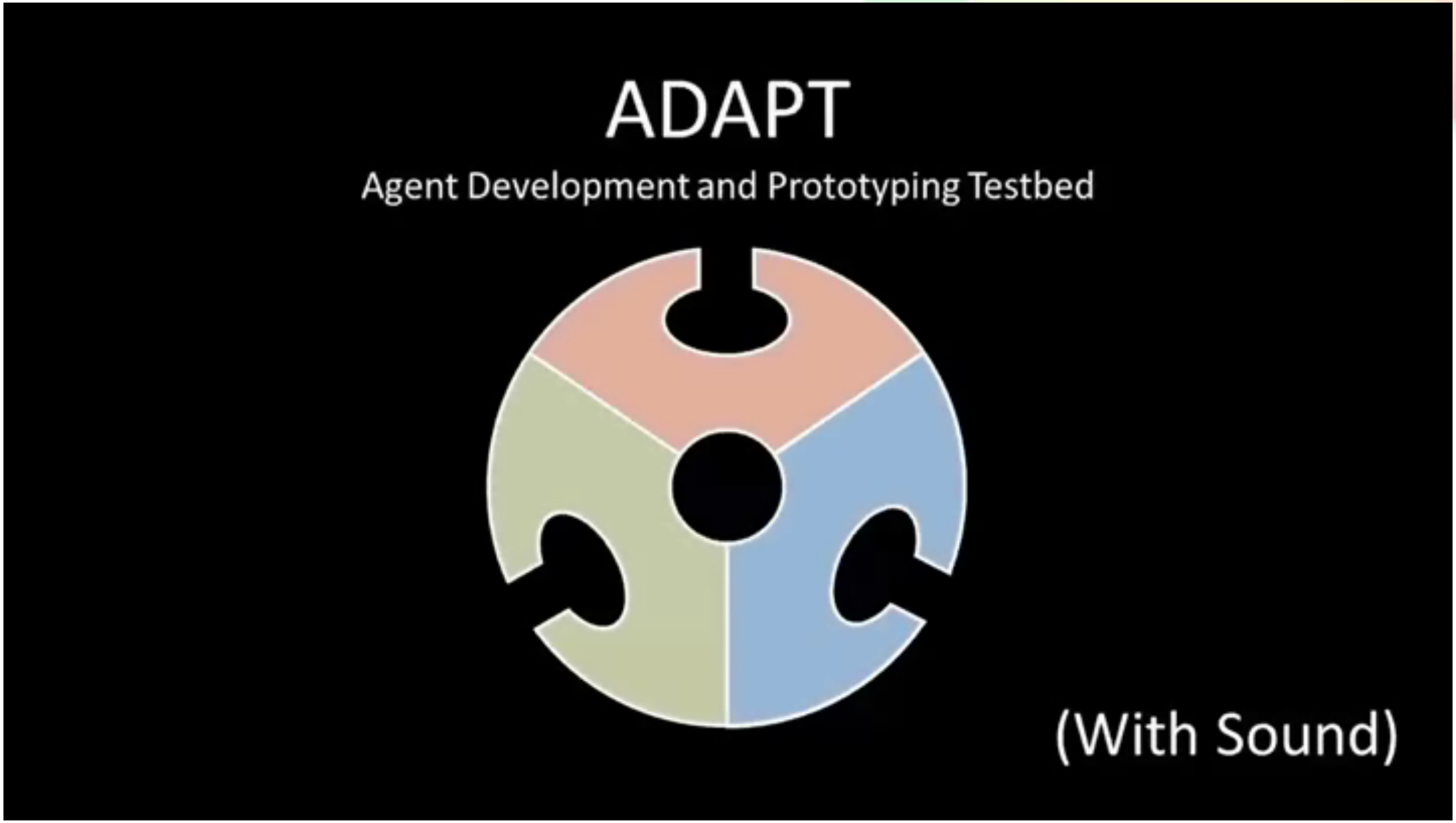
Parameterizing Behavior Trees



Alexander Shoulson, Francisco Garcia, M. Jones, Norman I. Badler

Fourth International Conference on Motion in Games (MIG), 2011

ADAPT Animations



Behavior

Functional Crowds and Psychological models

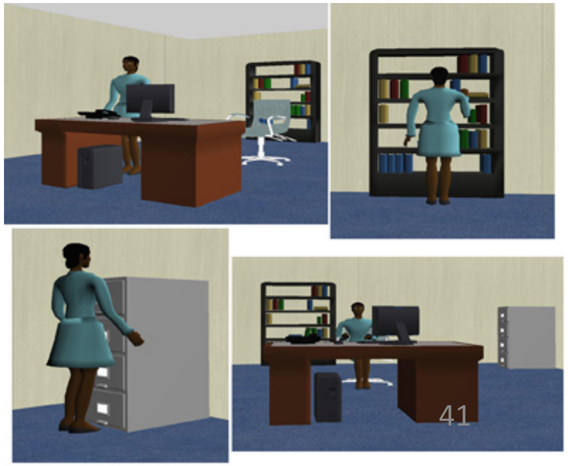
Jan Allbeck
George Mason University

POPULATIONS WITH PURPOSE

- Allbeck, J.M. CAROSA: A Tool for Authoring NPCs. In Proceedings of Motion in Games. Springer, 2010, pages 182-193.
- Allbeck, J.M. and Badler, N.I. Simulating Human Activities for Synthetic Inputs to Sensor Systems. In Distributed Video Sensor Networks. B. Bhanu, C.V. Ravishankar, A.K. Roy-Chowdhury, H. Aghajan, and D.Terzopoulos (Eds). Springer. 2011, pages 193-206.
- Li, W. and Allbeck, J.M. Populations with Purpose. In Proceedings of Motion in Games. Springer, pages 133-144, 2011.

Goal

- *Functional crowds* that are feasibly created and modified by non-programmers.
  - Heterogeneous: plausible, contextual variations in behaviors
  - Meaningful interactions with environment and other agents
  - *Assumes underlying crowd simulator*



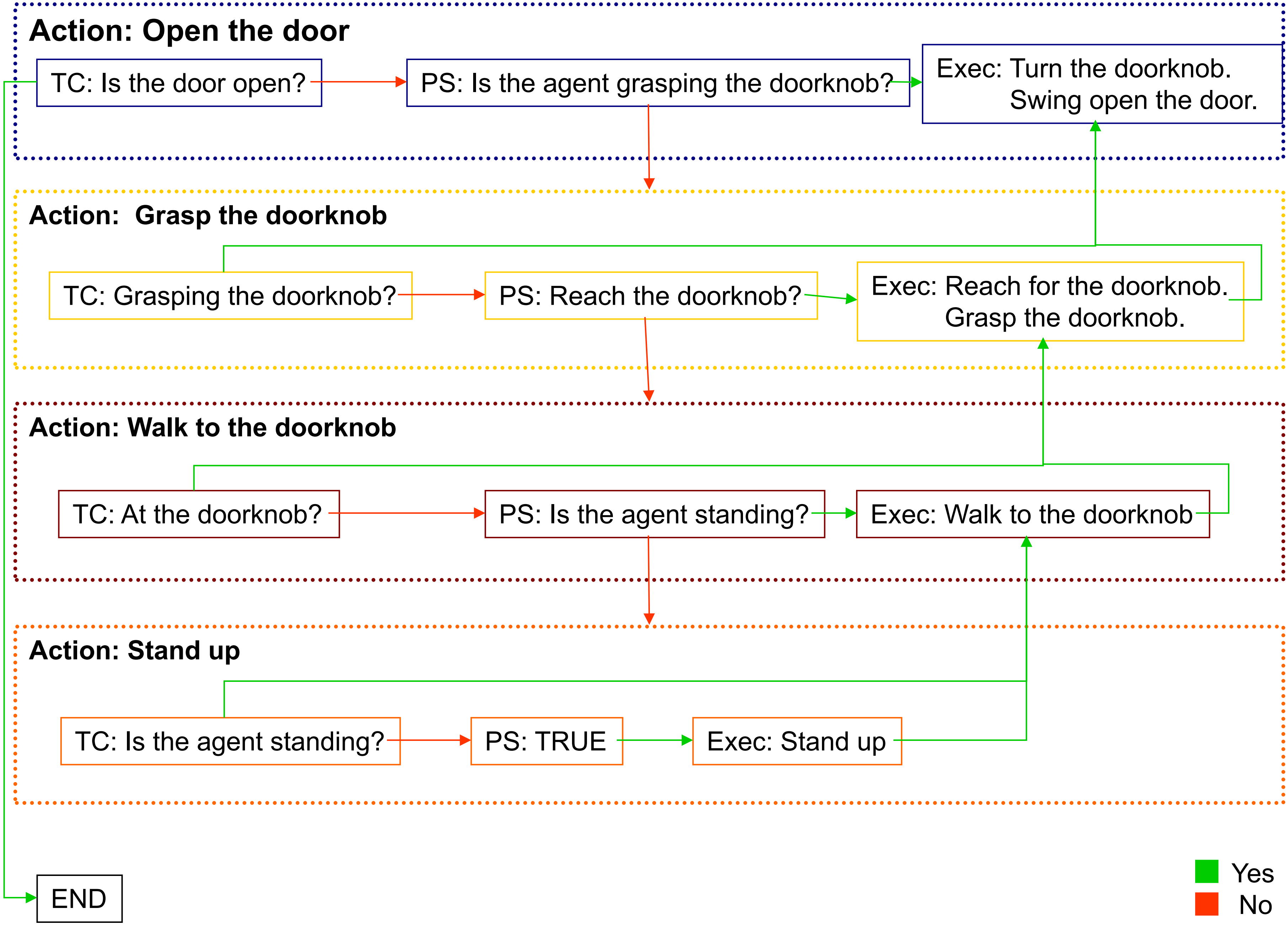
Autonomous Pedestrians
(Shao and Terzopoulos, Graphical Models, 2007)

CAROSA (Allbeck)

- Use a Parameterized Action Representation (PAR) to add semantics of actions, objects, and agents.
- Construct a resource manager to allocate object participants.
- Define four types of actions (scheduled, reactive, need-based and aleatoric) as mechanisms for behavior selection.
- Create mechanisms for suspending and preempting actions to promote user interaction.
- Use roles to specify behaviors at a higher level.
- Create richer *natural* behaviors through the addition of other social psychological models (e.g. use need levels to establish action priorities)

PAR Actions

- *core semantics:* motion, force, state-change, paths
- *participants:* agent, objects
- *purpose:* state to achieve, action to generate, etc.
- *manner:* how to perform action (e.g. "carefully")
- *type:* aleatoric, reactive, need-based
- *duration:* timing, iteration, or extent; e.g., "for 6 seconds", "between 5 and 6 times"
- *sub-steps:* actions to perform to accomplish action (includes parallel constructs)
- *next-step:* next action to be performed
- *super-step:* parent action
- *conditions: prior, post*



Action: Open the door
TC: Is the door open?
PS: Is the agent grasping the doorknob?
Exec: Turn the doorknob.
Swing open the door.
Action: Grasp the doorknob
TC: Grasping the doorknob?
PS: Reach the doorknob?
Exec: Reach for the doorknob.
Grasp the doorknob.
Action: Walk to the doorknob
TC: At the doorknob?
PS: Is the agent standing?
Exec: Walk to the doorknob
Action: Stand up
TC: Is the agent standing?
PS: TRUE
Exec: Stand up
END
Yes
No

Resource Manager

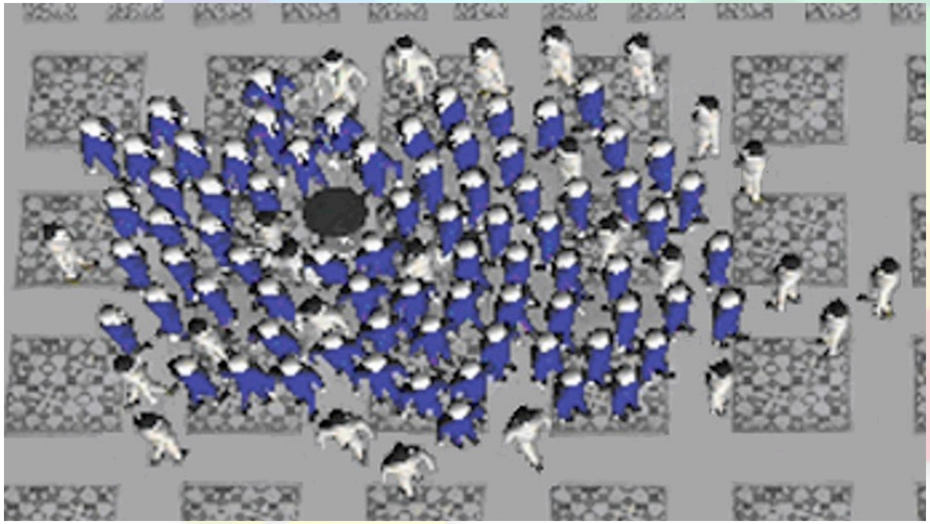
- Set up resources as a part of environment loading
- Associate resources with spaces (e.g. rooms)
- Allocate object participants for actions
- Take into account: object types, object states and properties, possessions, habits, preferences, ease of access, knowledge of environment
- Allocate automatically as a part of assigning actions to agents (or groups of agents) and process them for execution
- Automatically update the state of objects and de-allocate resources as post assertions of actions
- Failure is captured and conveyed to the agent process

Action Types

- Mechanisms for behavior selection
- Scheduled: arise from specified roles for individuals or groups
- Reactive: are triggered by contextual events or environmental constraints
- Need-based: arise from explicit goals and priorities
- Aleatoric: are random but structured by choices, distributions, or parametric variations

Summary

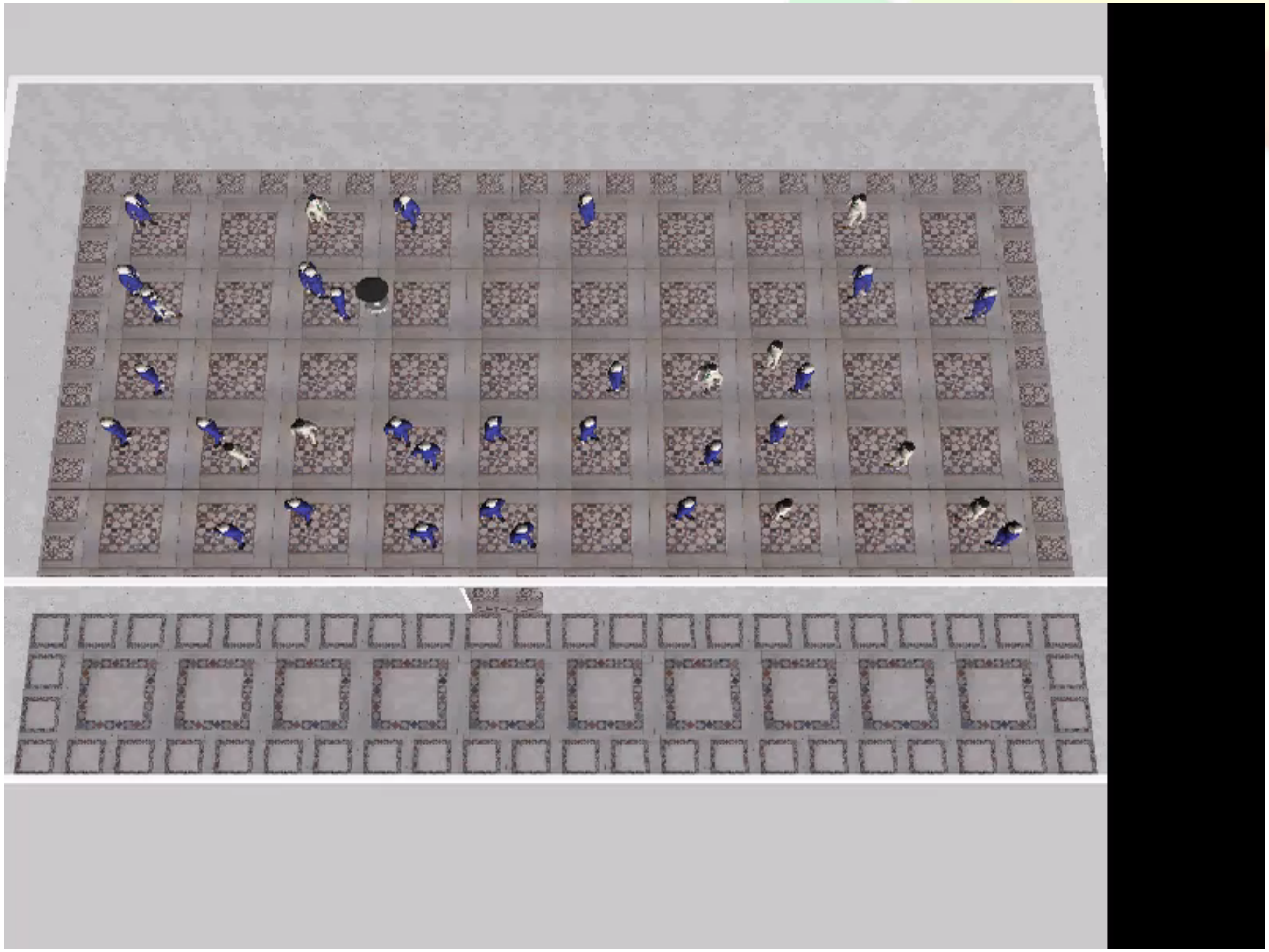
- *Functional crowds* are heterogeneous populations in which agents have meaningful interactions with their environment.
- Representing the semantics of actions and objects facilitates authoring (control vs. autonomy).
- Simple behavior selection mechanisms can lead to interesting, complex scenes.
- Defining roles, along with personality types and needs, can promote more consistent, compelling long term behaviors



HOW THE OCEAN PERSONALITY MODEL AFFECTS THE PERCEPTION OF CROWDS

- Durupinar, J. Allbeck, N. Pelechano, and N. Badler. Creating Crowd Variation with the OCEAN Personality Model. Proceedings of Autonomous Agents and Multi-Agents Systems 2008. pp 1217-1220.
- Durupinar, F., Pelechano, N., Allbeck, J., Gudukbay, U., and Badler, N. The Impact of the OCEAN Personality Model on the Perception of Crowds. IEEE Computer Graphics and Applications. vol. 31, no. 3, pp. 22-31, May/June, 2011.

Personalities



Five Factor (OCEAN) Model of Personality

- Personality is a pattern of a person’s behavioral, temperamental, emotional, and mental traits.
- Openness (closed): imaginative and creative
- Conscientious (not conscientious): organized and careful
- Extroverted (introverted): outgoing and sociable
- Agreeable (disagreeable): friendliness and generosity
- Neurotic (stable): emotional instability and negative emotions

Representation

- An agent personality: $\pi = < \Psi_{O,} \Psi_{C,} \Psi_{E,} \Psi_{A,} \Psi_{N} >$
- Distribution: $\Psi_i = N\left(\mu_i, {\sigma_i}^2\right), for\ i \in \{O, C, E, A, N\}$ where $\mu \in [0, 1], \sigma \in [-0.1, 0.1]$
- Behavior:
  - $\beta = (\beta_1, \beta_2, \dots, \beta_n)$
  - $\beta_j = f(\pi), for\ j = 1, \dots, n$

Parameter Mapping

Agent behavior	Personality factor	OCEAN
Leadership	Assertive, social, unsocial, calm, fearful	E, N
Trained or untrained	Informed, ignorant	O
Communication	Social, unsocial	E
Panic	Oversensitive, fearful, calm, orderly, predictable	N, C+
Impatience	Rude, assertive, patient, stubborn, tolerant, orderly	E+, C, A
Pushing	Rude, kind, harsh, assertive, shy	A, E
Right preference	Cooperative, predictable, negative, contrary, changeable	A, C
Avoidance or personal space	Social, distant	E
Waiting radius	Tolerant, patient, negative	A
Waiting timer	Kind, patient, negative	A
Exploring environment	Curious, narrow	O
Walking speed	Energetic, lethargic, vigorless	E
Gesturing	Social, unsocial, shy, energetic, lethargic	E

Panic

- Linked to stability and conscientiousness

$$\beta_i^{\text{Panic}} = \omega_{\text{NP}} \Psi_i^{\text{N}} + \omega_{\text{CP}} f(\Psi_i^{\text{C}})$$

$$f(\Psi_i^{\text{C}}) = \begin{cases} -2\Psi_i^{\text{C}} + 2 & \text{if } \Psi_i^{\text{C}} \geq 0, \\ 0 \text{ otherwise} \end{cases}$$

where $\beta_i^{\text{Panic}} \propto \text{N}$, $\beta_i^{\text{Panic}} \propto^{-1} \text{C+}$, and $\beta_i^{\text{Panic}} \in [0, 1]$

Pushing

- Disagreeable and extroverted agents tend to push others

$$P_i(\text{Pushing}) = \omega_{\text{EP}} {\Psi_i}^{\text{E}} + \omega_{\text{AP}} (1 - {\Psi_i}^{\text{A}})$$

$${\beta_i}^{\text{Pushing}} = \begin{cases} 1 \text{ if } P_i(\text{Pushing}) \geq 0.5 \\ 0 \text{ otherwise} \end{cases}$$

where $P_i(\text{Pushing}) \propto \text{E}$, $P_i(\text{Pushing}) \propto^{-1}$ A, and ${\beta_i}^{\text{Pushing}} \in \{0,1\}$

Waiting Radius

- Influenced by kindness and consideration
- Linked to agreeableness

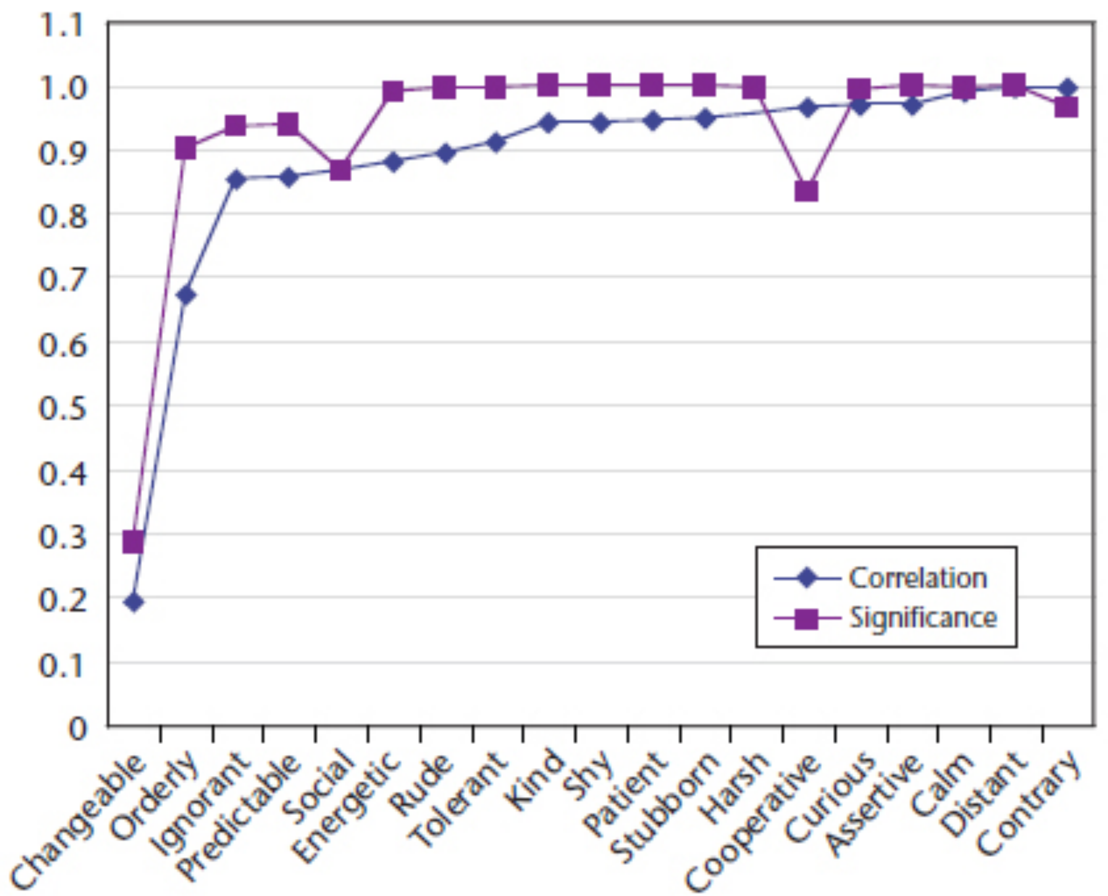
$$\beta_i^{\text{WaitingRadius}} = \begin{cases} 0.25 & \text{if } \Psi_i{}^{\text{A}} \in \left[\frac{0}{3}\frac{1}{3}\right) \\ 0.45 & \text{if } \Psi_i{}^{\text{A}} \in \left[\frac{1}{3}\frac{2}{3}\right] \\ 0.65 & \text{if } \Psi_i{}^{\text{A}} \in \left(\frac{2}{3}\frac{3}{3}\right] \end{cases}$$

where $\beta_i^{\text{WaitingRadius}} \propto \text{A}$ and $\beta_i^{\text{WaitingRadius}} \in \{0.25, 0.45, 0.65\}$

Evaluation

- 15 videos
  - Various OCEAN model settings
  - Evacuation drills, cocktail parties, museum galleries
- Map HiDAC parameters to OCEAN factors using trait-descriptive adjectives
- Determine correspondence between our mapping and users' perception of traits
- 70 participants (21 female and 49 males, ages 18-30)
- Shown videos and complete questionnaire

Analysis



1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Correlation
Significance
Changeable
Orderly
Ignorant
Predictable
Social
Energetic
Rude
Tolerant
Kind
Shy
Patient
Stubborn
Harsh
Cooperative
Curious
Assertive
Calm
Distant
Contrary