Software Architecture for Drone Simulation in 3D

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1 Context

2 SARL and AirSim

3 Introducing a framework for agent-based simulation

4 Defining Collision Avoidance Behavior

5 Results and Performance Benchmarks
1. Context

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5. Results and Performance Benchmarks
1. **Security and Privacy:** How to guarantee the security and confidentiality of information captured by drones?

2. **Safety:** How to guarantee the continuous and safe operation of drones?

3. **Traffic Regulation:** What are the regulations to implement? At what level (international, EU, national, local)?

4. **Traffic Management:** How to control the air traffic and its fluidity?

5. **Measuring the impact:** of drone introduction on socio-economic and environmental aspects.
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Multiagent System in SARL

A *collection of agents* interacting together in a collection of *shared distributed spaces*.

### 4 main concepts
- Agent
- Capacity
- Skill
- Space

### 3 main dimensions
- **Individual**: the Agent abstraction (Agent, Capacity, Skill)
- **Collective**: the Interaction abstraction (Space, Event, etc.)
- **Hierarchical**: the Holon abstraction (Context)

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[http://www.sarl.io](http://www.sarl.io)
AirSim is:
an open-source simulation platform developed by Microsoft

**Major Characteristics**

- Focuses on drone and car simulation.
- Manages the physics of the world.
- Simulates sensors, e.g. laser range finder.
- Provides an API to allow sending control commands to the vehicles.
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Agent Environment
- Resources, services, objects
- Rules, laws
- Physical structures (spatial and topological)
- Communication structures (stigmergy, implicit communication)
- Social structure

Direct interaction
Perceptions Actions
Introducing a framework for agent-based simulation

Defining Collision Avoidance Behavior

Results and Performance Benchmarks
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GENERAL AGENT-BASED SIMULATION
ARCHITECTURE

Avatar
Immersed
User

Agent

Direct interaction

Perceptions

Actions

Environment
- Resources, services, objects
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Simulator Controller

Observer

Change events

Rendering Software Modules
(1D, 2D or 3D)

Introducing a framework for agent-based simulation
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Defining Collision Avoidance Behavior

Results and Performance Benchmarks
State variables of the decisional component
Readable/modifiable only by the agent

State variables of the physical component
Readable by the agent
Modifiable by the environment
1. An agent does not change the state of the environment directly.
2. Agent gives a state-change expectation to the environment: the influence.
3. Environment gathers influences, and solves conflicts among them for obtaining its reaction.
4. Environment applies reaction for changing its state.
SARL-AIRSIM ARCHITECTURE

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1. **Link agents to vehicles:**
   - Receive the perceptions of each vehicle and dispatch them to linked agents
   - Collect and transmit the influences from the agents to AirSim

2. **Manage the simulation schedule**
The agent has the capacity to use its body.
The body supports the interactions with the environment.

```scala
event Perception {
  val object : Object
  val relativePosition : Vector
}

capacity EnvironmentInteraction {
  def moveTheBody(motion : Vector)
  def move(object : Object, motion : Vector)
  def executeActionOn(object : UUID, actionName : String, parameters : Object*)
}

skill PhysicBody implements EnvironmentInteraction {
  val env : UUID
  val body : UUID

  def moveTheBody(motion : Vector) {
    move(this.body, motion)
  }

  def move(object : UUID, motion : Vector) {
    emit(new MotionInfluence(object, motion)) [UUID == this.env]
  }

  def executeActionOn(object : UUID, actionName : String, parameters : Object*) {
    emit(new ActionInfluence(object, actionName, parameters)) [UUID == this.env]
  }
```
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“A sensory stimulus causes a behavioral reaction that depends on the personal aims; and

It is chosen from a set of behavioral alternatives with the objective of utility maximization.”
Context: SARL and AirSim

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Stimulus ➔ Psychological/Mental Processes ➔ Reaction

Body Attributes

Perceptions

Internal Properties/Aims

- Information Processing
- Decision
- Motivation to Act

Physical realization:
- behavioral change
- action

Linear Motion Vector

Angular Motion Vector
The systematic temporal changes $d\vec{w}_\alpha/dt$ of the preferred velocity $\vec{w}_\alpha(t)$ of a drone $\alpha$ are described by a vectorial quantity $\vec{F}_\alpha(t)$.

This force represents the effect of the environment (e.g. other drones or borders) on the behavior of the described drone.

It is a quantity that describes the concrete motivation to act.

One can say that a drone acts as if it would be subject to external forces.
If a drone’s motion is not disturbed, it will walk into the desired direction $\vec{r}_\alpha(t)$ with a certain desired speed $v^0_\alpha$.

A deviation of the actual velocity $\vec{v}_\alpha(t)$ to the desired velocity $\vec{v}^0_\alpha(t) = v^0_\alpha \vec{e}_\alpha(t)$ due to necessary deceleration processes or avoidance processes leads to a tendency to approach $\vec{v}^0_\alpha(t)$ again within a certain relaxation time $\tau_\alpha$:

$$F^0_\alpha(\vec{v}_\alpha, v^0_\alpha \vec{e}_\alpha) = \frac{1}{\tau_\alpha} (v^0_\alpha \vec{e}_\alpha - \vec{v}_\alpha)$$
The motion of a drone $\alpha$ is influenced by other drones. It keeps a certain distance from other drones that depends on the drone density and the desired speed $v^0_\alpha$. The private sphere of each drone, which can be interpreted as territorial effect (Scheflen and Ashcraft, 1976), plays an essential role.

A drone normally feels increasingly uncomfortable the closer another drone $\beta$ is inside its private sphere. This results in repulsive effects of $\beta$ that can be represented by vectorial quantities $\vec{f}_{\alpha\beta}$. 
The total motivation of a drone is affected by:

- Its acceleration term $\vec{F}_0^\alpha (\vec{v}_\alpha, v_0^\alpha \vec{e}_\alpha)$
- The repulsion from mobile objects
- The repulsion from immobile objects
- The attraction to other objects
The total motivation for the drone $\alpha$ is:

$$
\vec{F}_\alpha(t) = \vec{F}_\alpha^0(\vec{v}_\alpha, \nu^0_\alpha \vec{e}_\alpha) + \sum_\beta \vec{F}_{\alpha\beta}(\vec{e}_\alpha, \vec{r}_\alpha - \vec{r}_\beta) + \sum_B \vec{F}_{\alpha B}(\vec{e}_\alpha, \vec{r}_\alpha - \vec{r}_B) + \sum_i \vec{F}_{\alpha i}(\vec{e}_\alpha, \vec{r}_\alpha - \vec{r}_i, t)
$$

- acceleration term
- mobile object repulsion term
- immobile object repulsion term
- attraction term

The social force model becomes:

$$
d\vec{w}_\alpha = \vec{F}_\alpha(t) + \text{fluctuations}
$$

The fluctuation term takes into account random variations of the behavior.
Problems with the Social Force Model

1. Difficult to define the attraction term: what is the attraction length, regarding the repulsive terms?
2. It may be difficult to reproduce the smooth trajectories that are followed by real Humans.

Introduction of sliding forces that hide the attractive force, and make the trajectory smoother.
The force to apply to each agent is:

$$\vec{F}_a = \vec{F} + w_a \cdot \delta_{\|\vec{F}\|} \cdot (\hat{p}_t - \hat{p}_a)$$

$$\vec{F} = \sum_{i \in M} U(t_c^i) \cdot \hat{S}_i$$

where:

- $\vec{F}$ is the collision-avoidance force.
- $\hat{S}_i$ is a sliding force.
- $t_c^i$ is the time to collision to object $i$.
- $U(t)$ is a scaling function of the time to collision.
- $M$ is the set objects around (including the other agents).
- $w_a$ is the weight of the attractive force.
- $\delta_x g$ is $g$ if $x \leq 0$, 0 otherwise.
The sliding force \( \vec{S}_j \) is:

\[
\vec{s}_j = (p_j - p_a) \times \hat{y}
\]

\[
\hat{S}_j = \text{sign}(\vec{s}_j \cdot (\vec{p}_t - p_a)) \cdot \vec{s}_j
\]

\( \hat{y} \) is the vertical unit vector.
How to scale $\hat{S}_j$ to obtain the repulsive force?

Many force-based models use a monotonic decreasing function of the distance to an obstacle.

But it does not support the velocity of the agent.

Solution: Use time-based force scaling function.

$$U(t) = \begin{cases} 
\frac{\sigma}{t^\phi} - \frac{\sigma}{t_{max}^\phi} & \text{if } 0 \leq t \leq t_{max} \\
0 & \text{if } t > t_{max}
\end{cases}$$

where:
- $t$ is the estimated time to collision.
- $t_{max}$ is the the maximum anticipation time.
- $\sigma$ and $\phi$ are constants, such that $U(t_{max}) = 0$
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FORCE-BASED SIMULATION OF DRONES IN AIRSIM

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Simulations can run in real-time with up to 50 drones (30 FPS on a good PC)

The current bottleneck is AirSim

It is still possible to increase the amount of drones (but it will not be in real-time anymore)

There is on-going work made to improve AirSim efficiency for multi-agents simulations
Thank you for your attention...
Appendix
GITHUB REPOSITORIES

- http://github.com/alexandrelombard/sarl-airsim-interface
- http://github.com/alexandrelombard/airsim-jvm-api


