Navigation
IML

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ENIB

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Goal

Navigation

▷ determine paths to go from one point to an other.

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Mesh
Graph

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Classical approaches
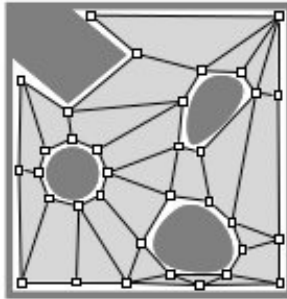Video games
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SGNG

Mesh
Graph

FIGURE – A simple environment (obstacles are in dark grey) represented by a mesh. The avatar can navigate in the zone defined by the mesh (in grey) because it knows there are no obstacles in this zone. Different algorithms can be used to find optimal paths.

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FIGURE – A simple environment (obstacles are in dark grey) represented by a mesh. The avatar can navigate in the zone defined by the mesh (in grey) because it knows there are no obstacles in this zone. Different algorithms can be used to find optimal paths.

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Problems

▷ requires an algorithm to find the optimal path between 2 points

▷ a path which may not be natural or believable

▷ All the meshes used to render the environment are too complex for agents to handle.

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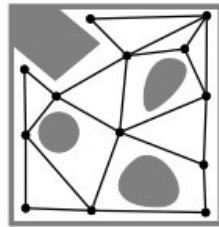Classical approaches
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FIGURE – A simple environment (obstacles are in grey) represented by a graph. Nodes are represented by circles and edges by black lines. An avatar can move from one node to another only if the nodes are connected by an edge. Usually, an A* is used to find the path between two nodes.
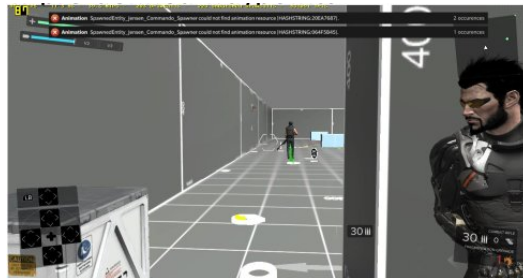

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Quake 3 Arena bots
Counter-Strike bots
Unreal Tournament's series bots
Valve bots

FIGURE – Classical bots are designed to follow pre-defined waypoints determined by the map designer.

Problems

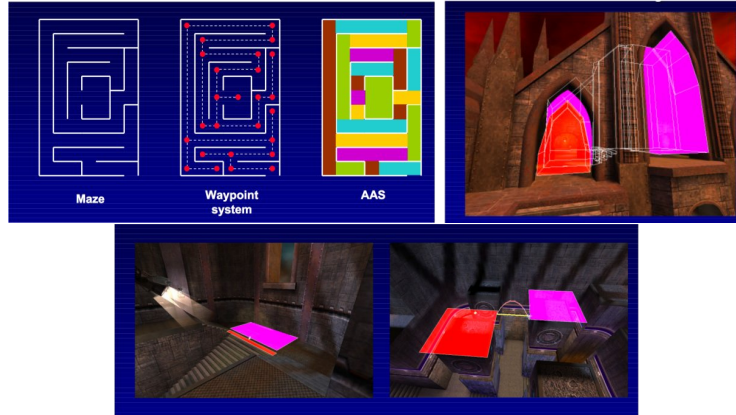▷ These bots need to have a waypoint file for each map, or a pathnode system embedded in the map.

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FIGURE – Quake 3 Arena bots use an area awareness system file to move around the map

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FIGURE – Quake 3 Arena bots use an area awareness system file to move around the map

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▷ The structure of the levels is analyzed, which is used to extract volumes of space that are navigable (e.g. walkable surfaces, swimming areas).

▷ A process then analyzes these areas for connections by simulating potential movement from each of them, and then clusters the areas together to allow hierarchical path-finding

▷ Quake 3 uses a form of pathfinding within the AAS graph that relies on the clusters of areas.

▷ Within these clusters, the paths to common destinations are pre-calculated and stored for later use.

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Counter-Strike bots use a waypoint file.

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Counter-Strike bots use a waypoint file.

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FIGURE – Unreal Tournament's series bots use a pathnode system embedded in the map to navigate

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FIGURE – Unreal Tournament's series bots use a pathnode system embedded in the map to navigate

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▷ To support the many community-created maps, some games include an automatic mesh generation system

▷ The first time users attempt to play a custom map with bots, the generation system will build a navigation file for that map. Starting at a player spawn point, walkable space is sampled by "flood-filling" outwards from that spot, searching for adjacent walkable points.

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▷ Finally, dynamic bots are able to dynamically learn levels and maps as they play. RealBot, for Counter-Strike, is an example of this. However, this learning is not guided by human behavior.

▷ Navigation points obtained will therefore not produce believable behavior. The paths the bots use to go from one point in the environment to another do not resemble those human players would take. This problem comes not from the decision-making process itself, but from the representation of the environment it uses. Indeed, the bots use navigation points in the environment which may not accurately or naturally represent how players use the same environment.

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Graph model

▷ incremental learning

▷ node
  ◇ position (x, y, z)
  ◇ cumulated error (measures how well the node represents its surroundings)

▷ edge
  ◇ links two nodes
  ◇ an age informing us when it was last activated.

▷ Principle : modify its graph for each input of the teacher's position in order to alter the graph to match the teacher's position. The model can add or remove nodes and edges if they do not fit the behavior and change the position of the nodes to better represent the teacher's position.

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Video : GNG.mp4
Video : moons.mov

GNG - algorithm

while *Number of nodes $\leq N_{max}$* **do**
    Get input position (a);
    Pick the closest (n_1) and the second closest nodes (n_2) (b);
    Create edge between n_1 and n_2 (c).;
    If an edge already existed, reset its age to 0.;
    Increase the error of n_1 (d);
    Move n_1 and its neighbors toward the input (e);
    Increase the age of all the edges emanating from n_1 by 1 (f);
    Delete edges exceeding a certain age (g);
    if *Iteration number is a multiple of η* **then**
        Find the maximum error node n_{max};
        Find the maximum error node n_{max2} among the neighbor of n_{max}
        (h);
        Insert node between n_{max} and n_{max2} (i);
        Decrease the error of n_{max} and n_{max2};
    end
    Decrease each node's error by a small amount (j);
end

(a)   (b)   (c)   (d)

(e)   (f)   (g)   (h)

(i)   (j)

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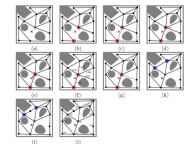
```python
import numpy as np
from scipy import spatial
import networkx as nx
import matplotlib.pyplot as plt
from sklearn import decomposition

class GrowingNeuralGas:

    def __init__(self, input_data):
        self.network = None
        self.data = input_data
        self.units_created = 0

    def find_nearest_units(self, observation):
        distance = []
        for u, attributes in self.network.nodes(data=True):
            vector = attributes['vector']
            dist = spatial.distance.euclidean(vector, observation)
            distance.append((u, dist))
        distance.sort(key=lambda x: x[1])
        ranking = [u for u, dist in distance]
        return ranking

    def prune_connections(self, a_max):
        for u, v, attributes in self.network.edges(data=True):
            if attributes['age'] > a_max:
                self.network.remove_edge(u, v)
        for u in self.network.nodes():
            if self.network.degree(u) == 0:
                self.network.remove_node(u)
```

```python
    def fit_network(self, e_b, e_n, a_max, l, a, d, passes=1, plot_evolution=
        False):
        # logging variables
        accumulated_local_error = []
        global_error = []
        network_order = []
        network_size = []
        total_units = []
        self.units_created = 0
        # 0. start with two units a and b at random position w_a and w_b
        w_a = [np.random.uniform(-2, 2) for _ in range(np.shape(self.data)[1])]
        w_b = [np.random.uniform(-2, 2) for _ in range(np.shape(self.data)[1])]
        self.network = nx.Graph()
        self.network.add_node(self.units_created, vector=w_a, error=0)
        self.units_created += 1
        self.network.add_node(self.units_created, vector=w_b, error=0)
        self.units_created += 1
```

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```python
def fit_network(self, e_b, e_n, a_max, l, a, d, passes=1, plot_evolution=
    False):
    ...
    # 1. iterate through the data
    sequence = 0
    for p in range(passes):
        print('   Pass #%d' % (p + 1))
        np.random.shuffle(self.data)
        steps = 0
        for observation in self.data:
            # 2. find the nearest unit s_1 and the second nearest unit s_2
            nearest_units = self.find_nearest_units(observation)
            s_1 = nearest_units[0]
            s_2 = nearest_units[1]
            # 3. increment the age of all edges emanating from s_1
            for u, v, attributes in self.network.edges_iter(data=True,
                    nbunch=[s_1]):
                self.network.add_edge(u, v, age=attributes['age']+1)
            # 4. add the squared distance between the observation and the
            #     nearest unit in input space
            self.network.node[s_1]['error'] += spatial.distance.euclidean(
                observation, self.network.node[s_1]['vector'])**2
```

```python
def fit_network(self, e_b, e_n, a_max, l, a, d, passes=1, plot_evolution=
    False):
    ...
            # 5 .move s_1 and its direct topological neighbors towards the
            #     observation by the fractions
            #     e_b and e_n, respectively, of the total distance
            update_w_s_1 = e_b * (np.subtract(observation, self.network.node
                [s_1]['vector']))
            self.network.node[s_1]['vector'] = np.add(self.network.node[s_1
                ]['vector'], update_w_s_1)
            update_w_s_n = e_n * (np.subtract(observation, self.network.node
                [s_1]['vector']))
            for neighbor in self.network.neighbors(s_1):
                self.network.node[neighbor]['vector'] = np.add(self.network.
                    node[neighbor]['vector'], update_w_s_n)

            # 6. if s_1 and s_2 are connected by an edge, set the age of
            #     this edge to zero
            #     if such an edge does not exist create it
            self.network.add_edge(s_1, s_2, age=0)
            # 7. remove edges with an age larger than a_max
            #     if this results in units having no emanating edges, remove
            #     them as well
            self.prune_connections(a_max)
```

```python
def fit_network(self, e_b, e_n, a_max, l, a, d, passes=1, plot_evolution=
    False):
    ...
                    # 8. if the number of steps so far is an integer multiple of
                    #    parameter l, insert a new unit
                    steps += 1
                    if steps % l == 0:
                        if plot_evolution:
                            self.plot_network('visualization/sequence/' + str(
                                sequence) + '.png')
                        sequence += 1
                        # 8.a determine the unit q with the maximum accumulated
                        #     error
                        q = 0
                        error_max = 0
                        for u in self.network.nodes_iter():
                            if self.network.node[u]['error'] > error_max:
                                error_max = self.network.node[u]['error']
                                q = u
                        # 8.b insert a new unit r halfway between q and its neighbor
                        #     f with the largest error variable
                        f = -1
                        largest_error = -1
                        for u in self.network.neighbors(q):
                            if self.network.node[u]['error'] > largest_error:
                                largest_error = self.network.node[u]['error']
                                f = u
                        w_r = 0.5 * (np.add(self.network.node[q]['vector'], self.
                            network.node[f]['vector']))
```

```python
def fit_network(self, e_b, e_n, a_max, l, a, d, passes=1, plot_evolution=
    False):
    ...
                        # 8.c insert edges connecting the new unit r with q and f
                        #     remove the original edge between q and f
                        self.network.add_node(r, vector=w_r, error=0)
                        self.network.add_edge(r, q, age=0)
                        self.network.add_edge(r, f, age=0)
                        self.network.remove_edge(q, f)
                        # 8.d decrease the error variables of q and f by multiplying
                        #      them with a
                        #     initialize the error variable of r with the new value
                        #      of the error variable of q
                        self.network.node[q]['error'] *= a
                        self.network.node[f]['error'] *= a
                        self.network.node[r]['error'] = self.network.node[q]['error'
                            ]
                    # 9. decrease all error variables by multiplying them with a
                    #    constant d
                    error = 0
                    for u in self.network.nodes_iter():
                        error += self.network.node[u]['error']
                    accumulated_local_error.append(error)
                    network_order.append(self.network.order())
                    network_size.append(self.network.size())
                    total_units.append(self.units_created)
                    for u in self.network.nodes_iter():
                        self.network.node[u]['error'] *= d
                        if self.network.degree(nbunch=[u]) == 0:
                            print(u)
```

```python
def fit_network(self, e_b, e_n, a_max, l, a, d, passes=1, plot_evolution=
    False):
    ...
    plt.clf()
    plt.title('Accumulated local error')
    plt.xlabel('iterations')
    plt.plot(range(len(accumulated_local_error)), accumulated_local_error)
    plt.savefig('visualization/accumulated_local_error.png')
    plt.clf()
    plt.title('Global error')
    plt.xlabel('passes')
    plt.plot(range(len(global_error)), global_error)
    plt.savefig('visualization/global_error.png')
    plt.clf()
    plt.title('Neural network properties')
    plt.plot(range(len(network_order)), network_order, label='Network order'
        )
    plt.plot(range(len(network_size)), network_size, label='Network size')
    plt.legend()
    plt.savefig('visualization/network_properties.png')
```

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```python
def plot_network(self, file_path):
    plt.clf()
    plt.scatter(self.data[:, 0], self.data[:, 1])
    node_pos = {}
    for u in self.network.nodes_iter():
        vector = self.network.node[u]['vector']
        node_pos[u] = (vector[0], vector[1])
    nx.draw(self.network, pos=node_pos)
    plt.draw()
    plt.savefig(file_path)

def number_of_clusters(self):
    return nx.number_connected_components(self.network)
```

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```python
def cluster_data(self):
    unit_to_cluster = np.zeros(self.units_created)
    cluster = 0
    for c in nx.connected_components(self.network):
        for unit in c:
            unit_to_cluster[unit] = cluster
        cluster += 1
    clustered_data = []
    for observation in self.data:
        nearest_units = self.find_nearest_units(observation)
        s = nearest_units[0]
        clustered_data.append((observation, unit_to_cluster[s]))
    return clustered_data

def reduce_dimension(self, clustered_data):
    transformed_clustered_data = []
    svd = decomposition.PCA(n_components=2)
    transformed_observations = svd.fit_transform(self.data)
    for i in range(len(clustered_data)):
        transformed_clustered_data.append((transformed_observations[i],
                clustered_data[i][1]))
    return transformed_clustered_data
```

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```python
def plot_clusters(self, clustered_data):
    number_of_clusters = nx.number_connected_components(self.network)
    plt.clf()
    plt.title('Cluster affectation')
    color = ['r', 'b', 'g', 'k', 'm', 'r', 'b', 'g', 'k', 'm']
    for i in range(number_of_clusters):
        observations = [observation for observation, s in clustered_data if
                s == i]
        if len(observations) > 0:
            observations = np.array(observations)
            plt.scatter(observations[:, 0], observations[:, 1], color=color[
                    i], label='cluster #'+str(i))
    plt.legend()
    plt.savefig('visualization/clusters.png')

def compute_global_error(self):
    global_error = 0
    for observation in self.data:
        nearest_units = self.find_nearest_units(observation)
        s_1 = nearest_units[0]
        global_error += spatial.distance.euclidean(observation, self.network
                .node[s_1]['vector'])**2
    return global_error
```

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example

```
from gng import GrowingNeuralGas
from sklearn import datasets
from sklearn.preprocessing import StandardScaler

print('Generating data...')
data = datasets.make_moons(n_samples=2000, noise=.05)
data = StandardScaler().fit_transform(data[0])
print('Done.')
print('Fitting neural network...')
gng = GrowingNeuralGas(data)
gng.fit_network(e_b=0.1, e_n=0.006, a_max=10, l=200, a=0.5, d=0.995, passes=8,
    plot_evolution=True)
print('Found %d clusters.' % gng.number_of_clusters())
gng.plot_clusters(gng.cluster_data())
```
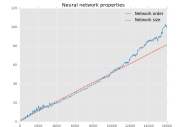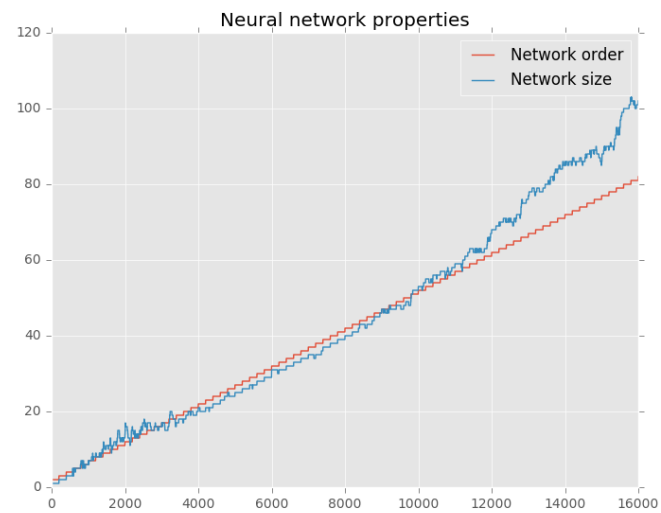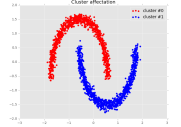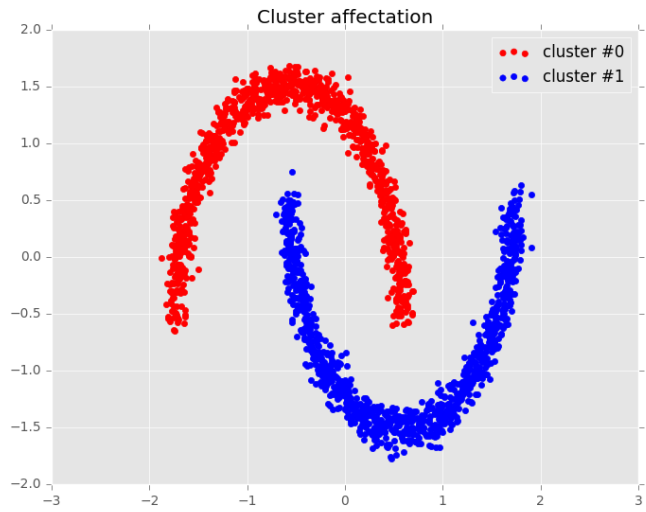
example

```
    Preparing data...
Done.
Fitting neural network...
    Pass #1
    Pass #2
    Pass #3
    Pass #4
    Pass #5
    Pass #6
    Pass #7
    Pass #8
Found 2 clusters.
```
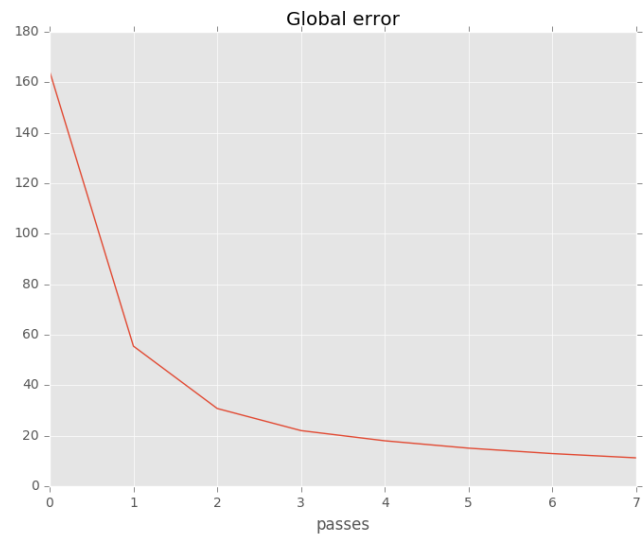
Cluster affectation

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Neural network properties

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Global error
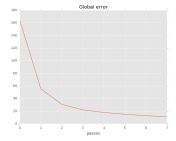
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Problems
▷ Fails to handle temporal series
▷ Grow up over the time (constant iteration insertion policy)

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SGNG : Pro

▷ Grow up over the time : a node should be inserted when the error of a node is superior to a parameter $\overline{Err}$ (add nodes only in the area just visited and add nodes only when the network fails to fit the data suitably).

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SGNG : Pro
▷ Grow up over the time : a node should be inserted when the error of a node is superior to a parameter $\overline{Err}$ (add nodes only in the area just visited and add nodes only when the network fails to fit the data suitably).

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SGNG - algorithm

```
nodes ← {}
edges ← {}
while teacher plays do
    (x,y,z) ← teacher's position
    if |nodes| = 0 or 1 then
        nodes ← nodes ∪ {(x,y,z,error=0)}
    end if
    if |nodes| = 2 then
        edges ← {(nodes,age=0)}
    end if
    n₁ ← closest((x,y,z),nodes)
    n₂ ← secondClosest((x,y,z),nodes)
    edge ← edges ∪ {{n₁,n₂},age=0)}

    n₁.error+=||(x,y,z)-n₁||
    Attract n₁ toward (x,y,z)
    ∀ edge ∈ edgesFrom(n₁), edge.age++
    Delete edges older than Āge
    Attract neighbors(n₁) toward (x,y,z)
    ∀ node ∈ nodes, node.error-=Err

    if n₁.error > E̅r̅r̅ then
        maxErrNei ← maxErrorNeighbour(n₁)
        newNode ← between(n₁,maxErrNei)
        n₁.error/=2
        maxErrNei.error/=2
        newError ← n₁.error+maxErrNei.error
        nodes ← nodes ∪ {(newNode,newError)}
    end if
```

SGNG : Application to video games

https://www.youtube.com/watch?v=HSKkr4CQYr8
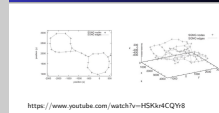
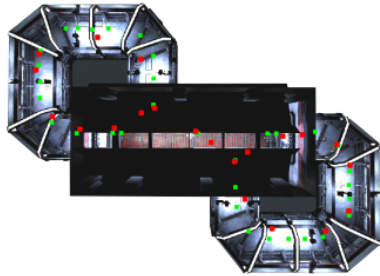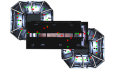# SGNG : Application to video games

FIGURE – Comparison of nodes learned by the SGNG (in red) with the navigation points placed manually by the game developers (in green). The environment viewed from above is visible in the background.

SGNG : Evaluation

Sensitivity

Sensitivity measures how successfully the SGNG represents the part of the environment the teacher used, which can be seen as true positives. $mindist(a, B)$ is the minimum distance between point a and the points in set B. We computed this measure using the following formula :

$$Sensitivity \propto \frac{1}{\sum_i mindist(NP_i, nodes)} \quad (1)$$

Where NP_i is the ith navigation point. The higher the value, the more sensitive the SGNG.

SGNG : Evaluation

Specificity

Specificity measures how much the SGNG did not represent the part of the environment the teacher did not use, which can be seen as true negatives. We computed this measure using the following formula :

$$Specificity \propto \frac{Number\ of\ Nodes}{\sum_i mindist(Node_i, NPs)} \quad (2)$$

The higher the value, the more specific the SGNG.

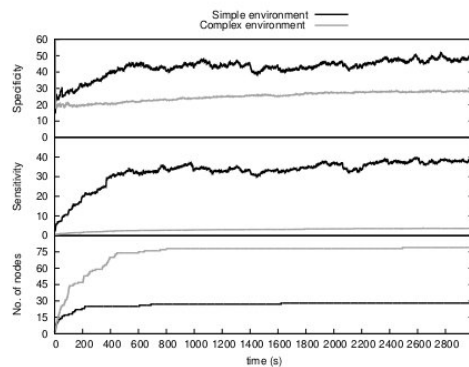## SGNG : Evaluation
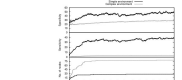

FIGURE – Time evolution of the SGNG number of nodes and the cumulated distance between the SGNG nodes and the navigation points.

SGNG : Evaluation

IML
└─SGNG

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Figure – Comparison of two SGNG learned on the same environment
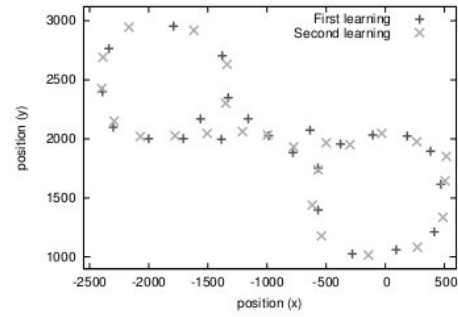after a very long training period of 10 hours.

FIGURE – Comparison of two SGNG learned on the same environment
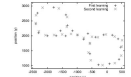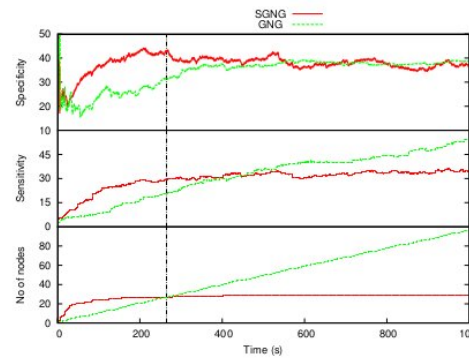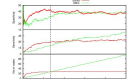after a very long training period of 10 hours.

SGNG : Evaluation

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└─SGNG : Evaluation

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SGNG : Référence

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Navigation
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11 septembre 2019