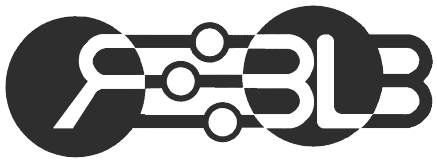


Robótica Evolutiva

Introducción a la Robótica Inteligente

Álvaro Gutiérrez

7 de mayo de 2025

a.gutierrez@upm.es

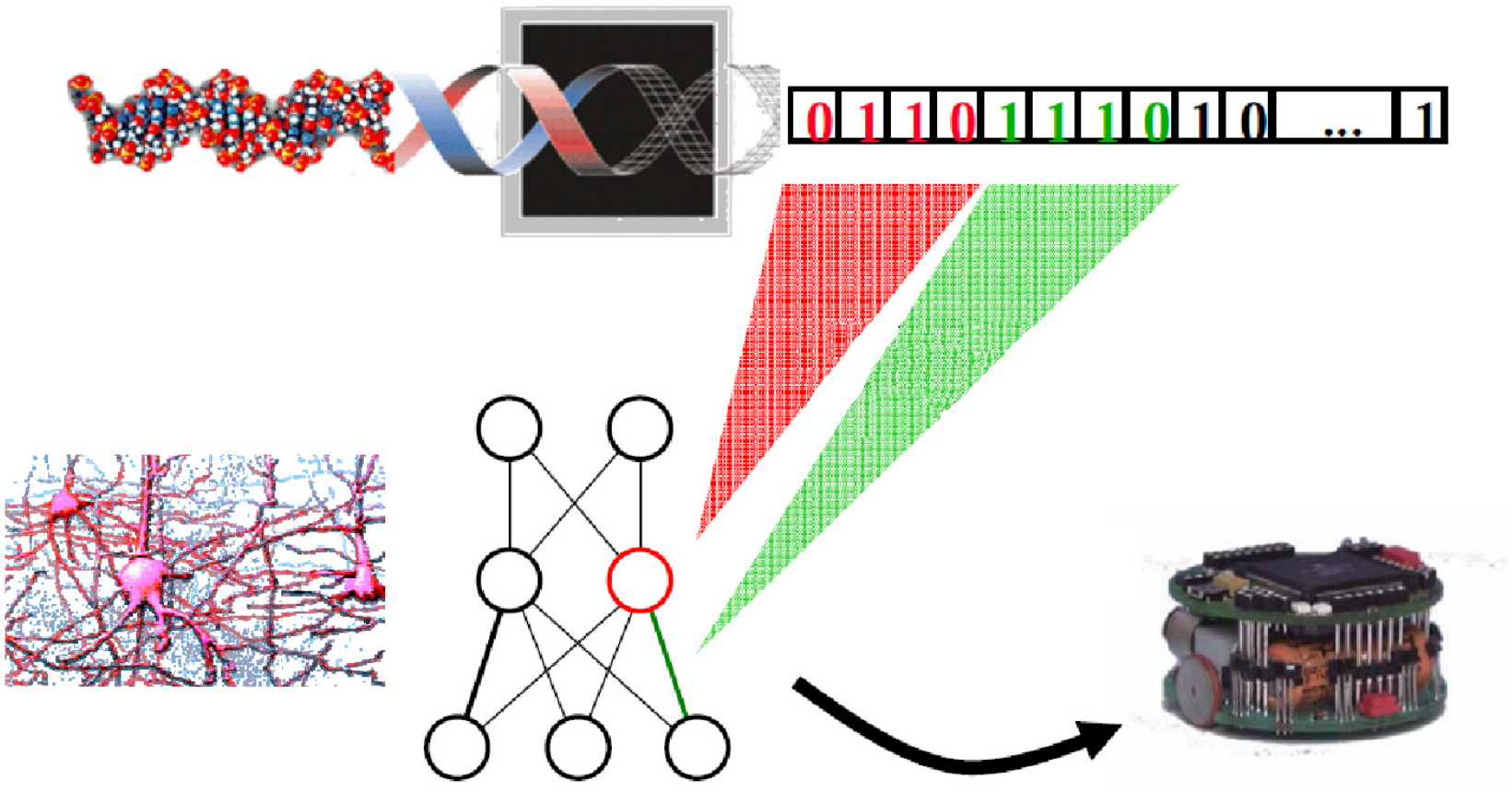
www.robolabo.etsit.upm.es

Índice

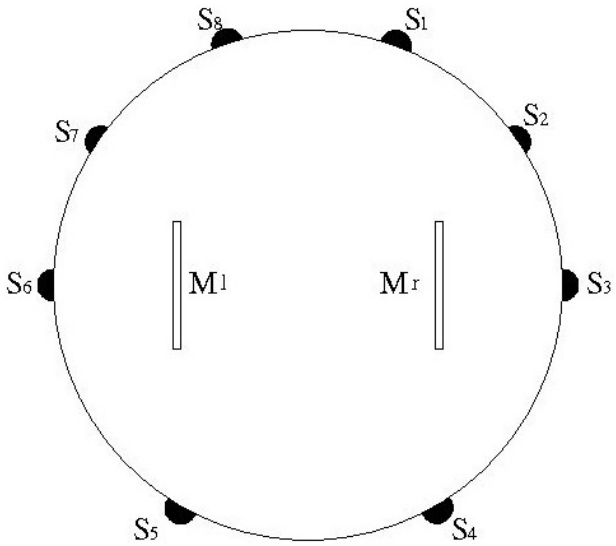
Robótica Evolutiva

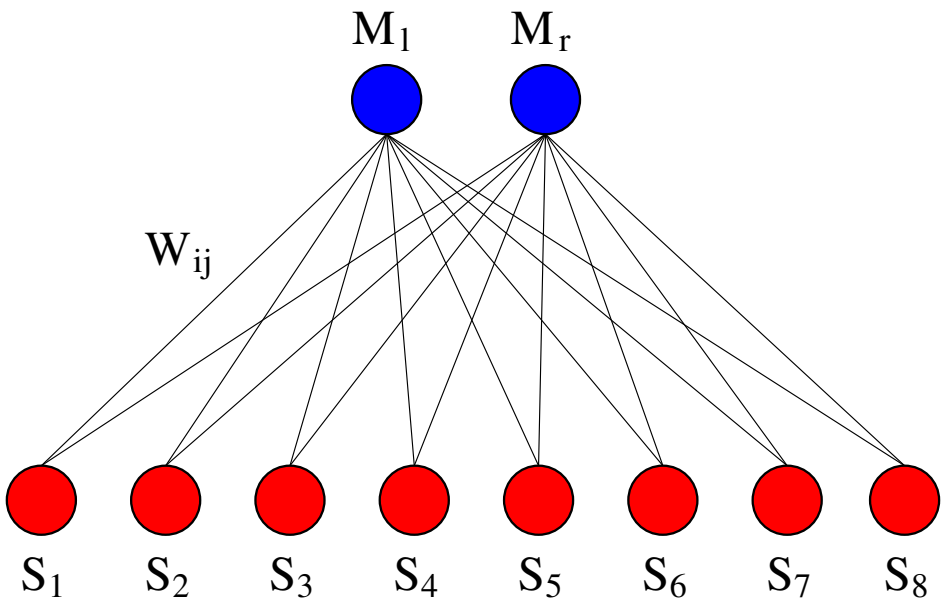
- La **Robótica Evolutiva** (RE) es la generación de **sistemas de control** (y/o morfologías) para robots autónomos basados en el principio **Darviniano** de reproducción selectiva del más adecuado
- **Motivación:** Es difícil diseñar sistemas autónomos usando técnicas ingenieriles porque la iteracción entre un robot autónomo y su entorno es compleja y difícil de predecir
- En la robótica evolutiva definimos los componentes del sistema de control (sensores y actuadores) y un criterio de selección, y dejamos a la evolución artificial descubrir los individuos más adecuados mientras el robot interactúa con el entorno

RE - Introducción

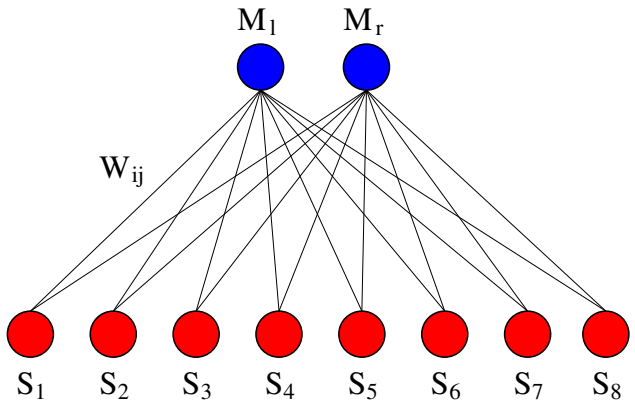


RE - Red Neuronal



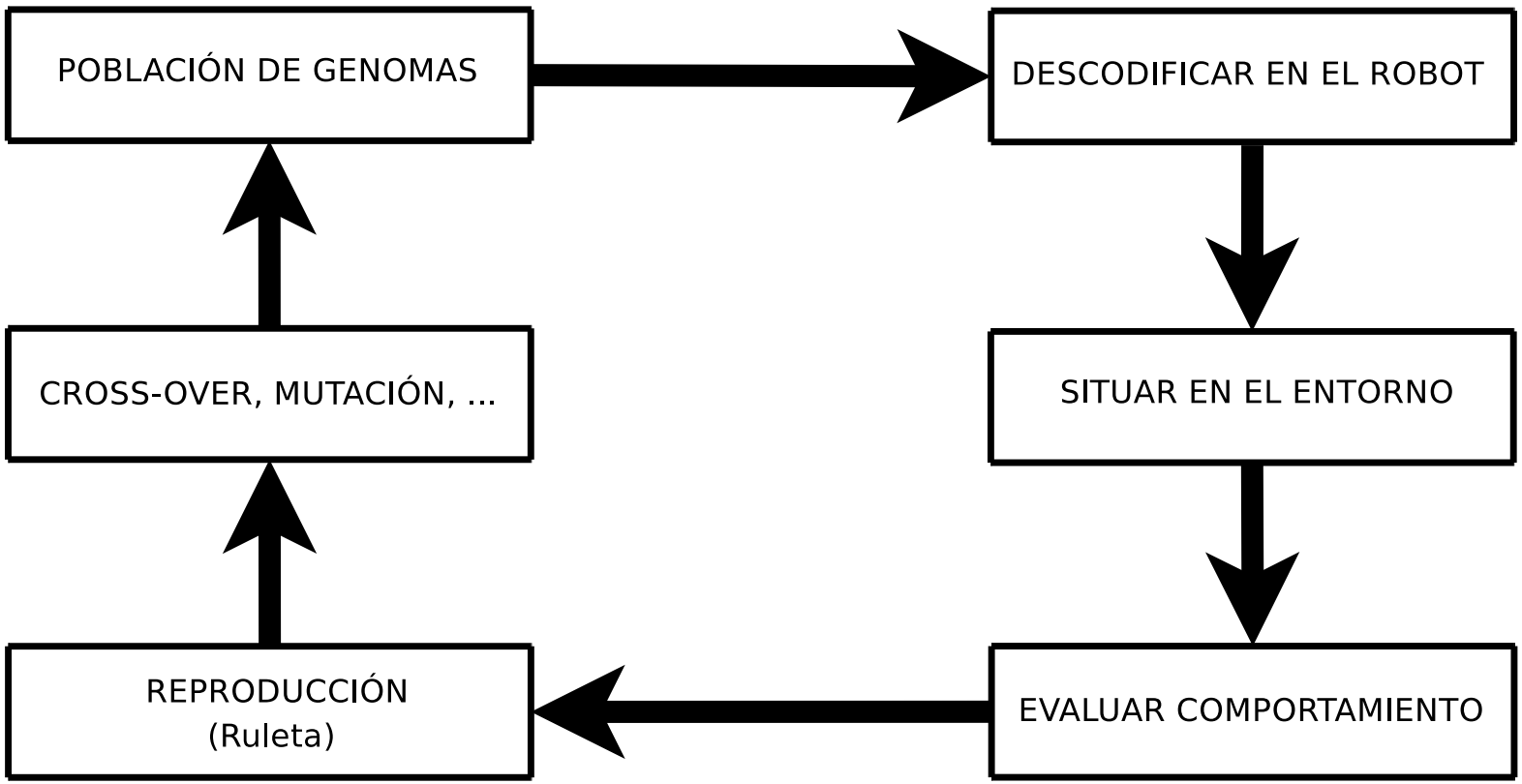


RE - Codificación

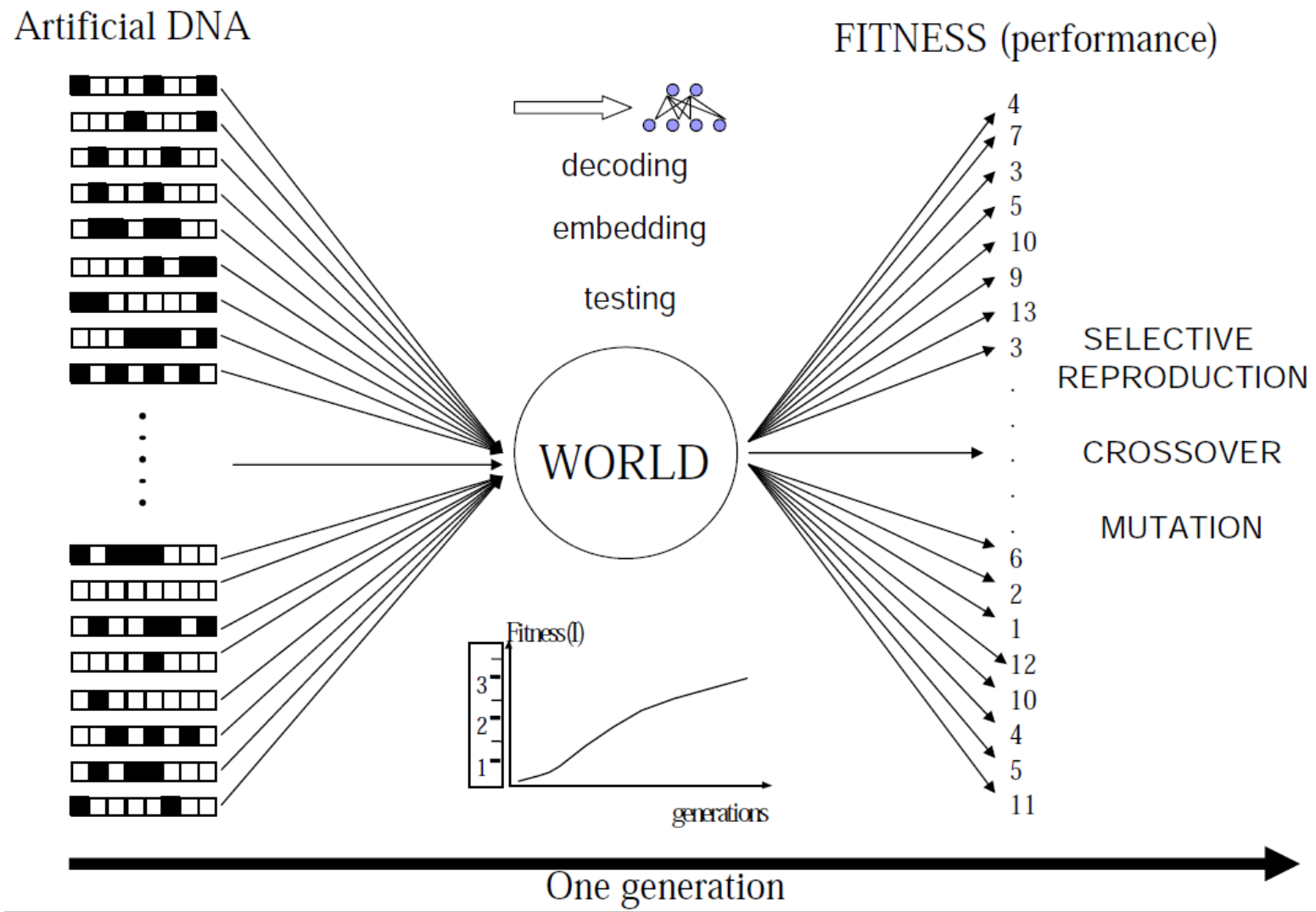


W_{11}	W_{12}	W_{13}	W_{14}	W_{15}	W_{16}	W_{17}	W_{18}	W_{21}	W_{22}	W_{23}	W_{24}	W_{25}	W_{26}	W_{27}	W_{28}

RE - Metodología

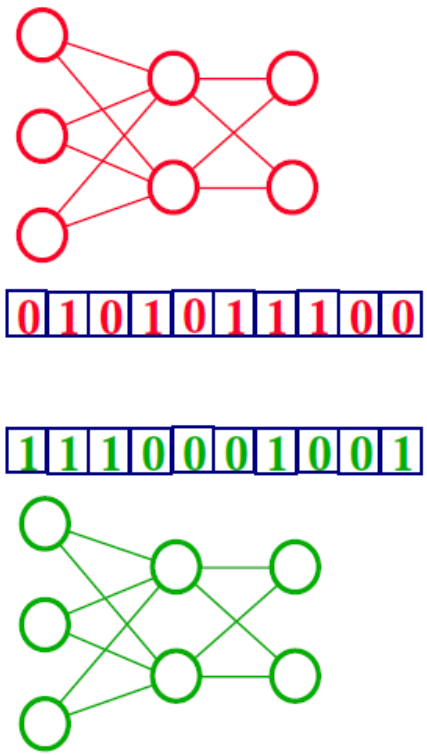


RE - Metodología

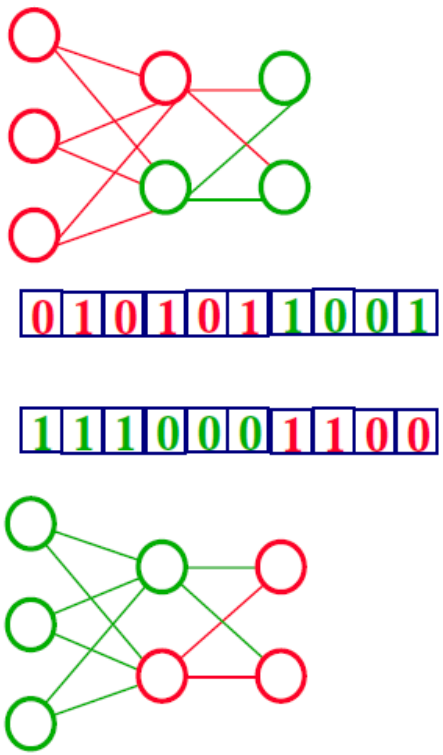


RE - Operadores

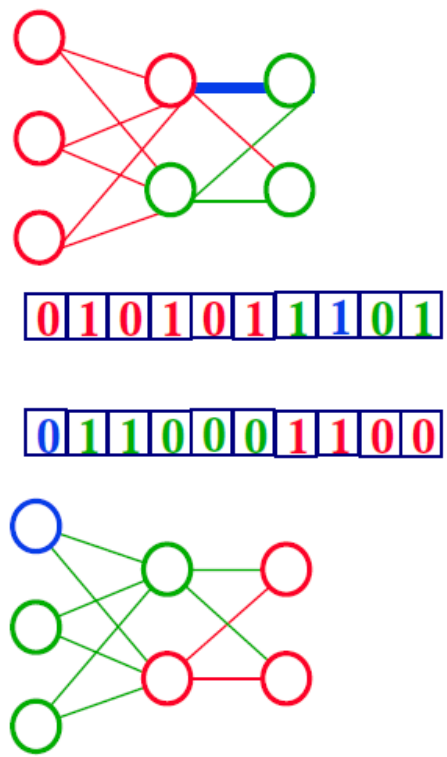
SELECTION



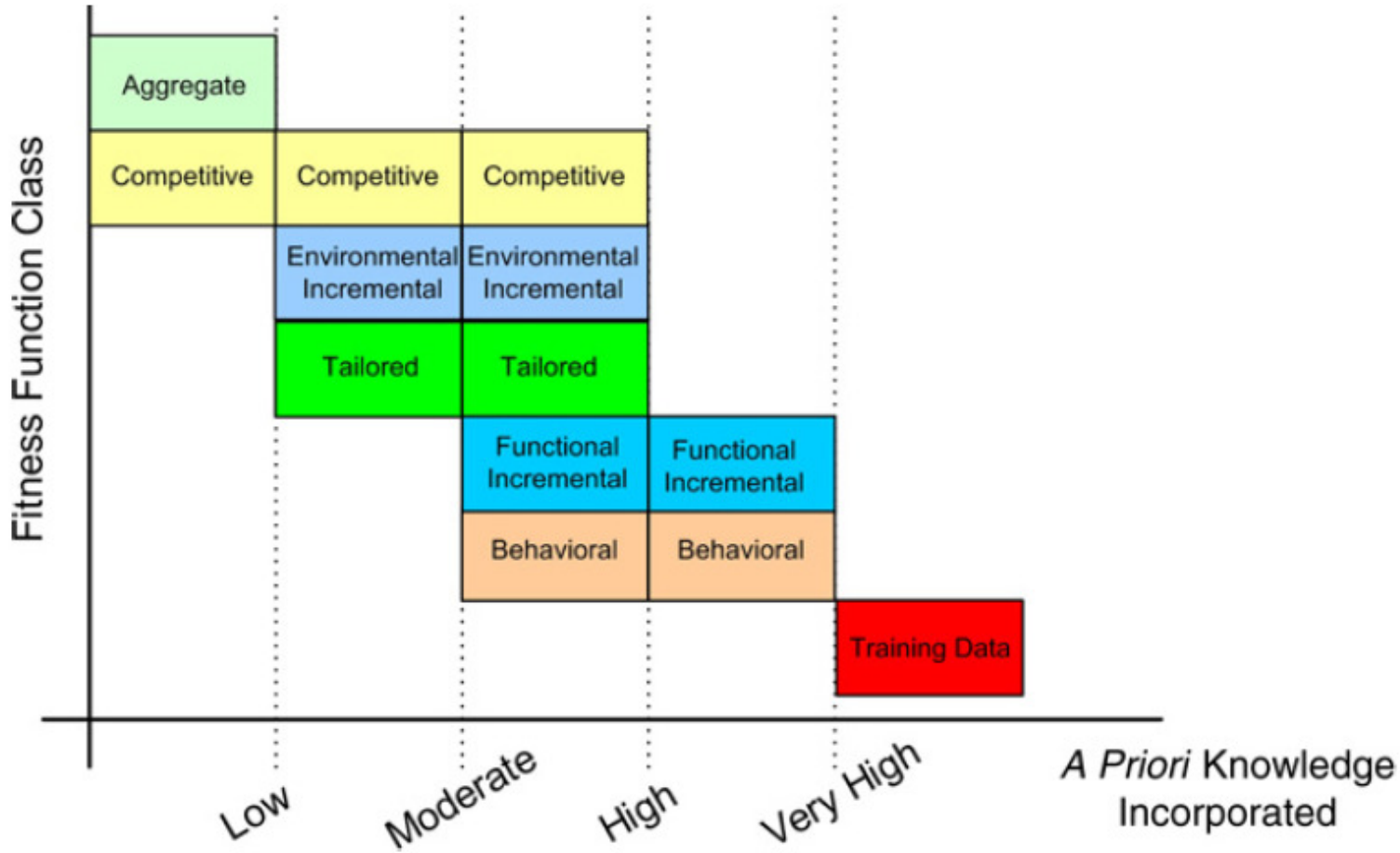
CROSSOVER



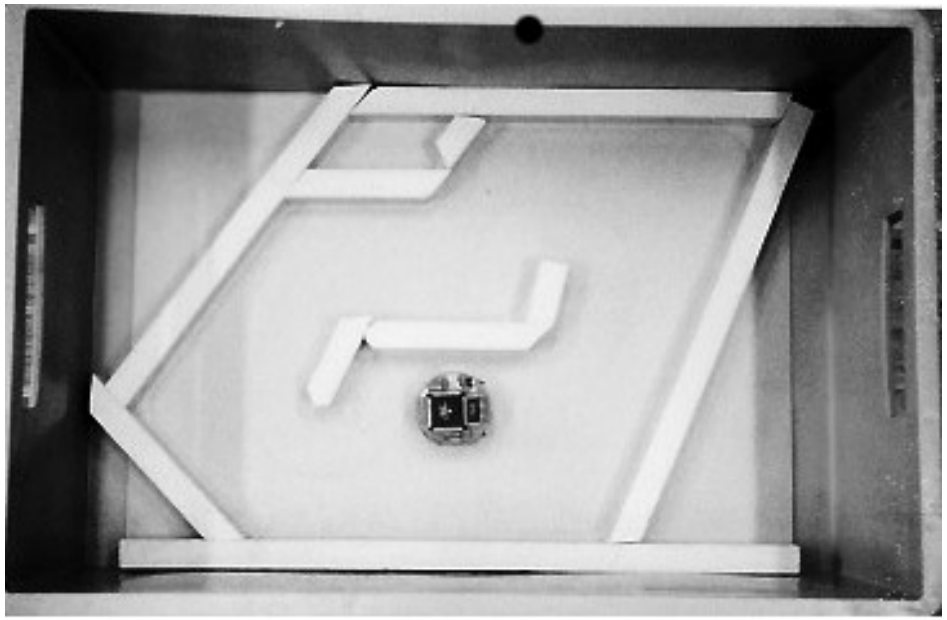
MUTATION



RE - Fitness


Fitness Function Class
Aggregate
Competitive
Competitive
Competitive
Environmental Incremental
Environmental Incremental
Tailored
Tailored
Functional Incremental
Functional Incremental
Behavioral
Behavioral
Training Data
Low
Moderate
High
Very High
A Priori Knowledge Incorporated

Evitador de Obstáculos



Automatic Creation of an Autonomous Agent: Genetic Evolution of a Neural Network Driven Robot (Floreano y Mondada, 1994)

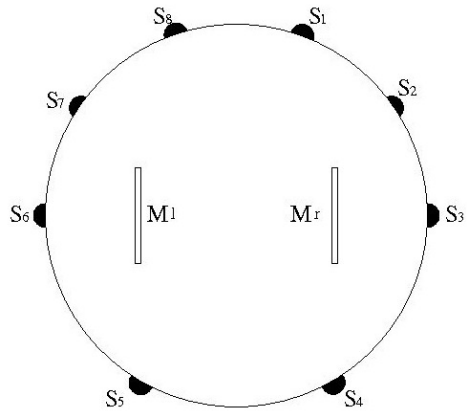
Evitador de Obstáculos

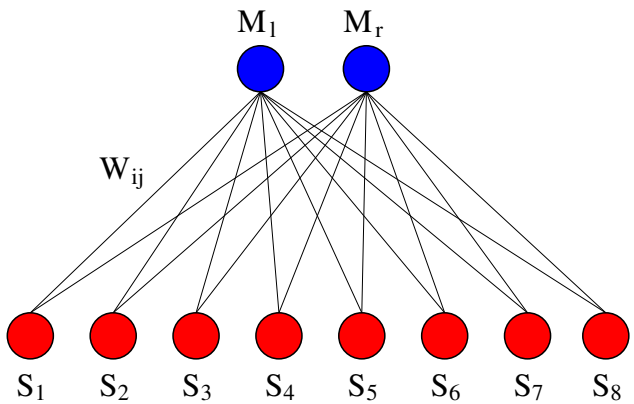
- 8 Sensores de Infrarrojo
- 2 Motores
- Perceptrón
- Neuronas: Sigmoide

$$n_i = \sum_j \omega_{ji} x_i$$

$$y_i = \frac{1}{1 + e^{-(n_i - \theta_i)}}$$

- Cromosoma:
  - Pesos de la red
  - Sesgos





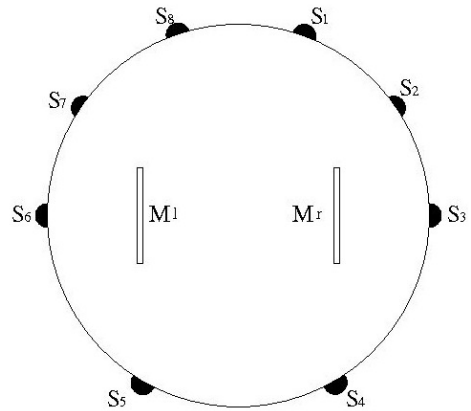
Evitador de Obstáculos

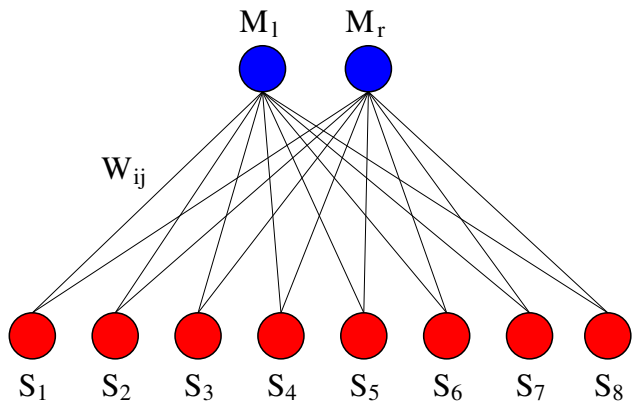
- 8 Sensores de Infrarrojo
- 2 Motores
- Perceptrón
- Neuronas: Sigmoide

$$n_i = \sum_j \omega_{ji} x_i$$

$$y_i = \frac{1}{1 + e^{-(n_i - \theta_i)}}$$

- Cromosoma:
  - Pesos de la red (16)
  - Sesgos (2)





Evitador de Obstáculos

- Función de Fitness

Evitador de Obstáculos

- Función de Fitness
- PROPUESTAS!!!!

Evitador de Obstáculos

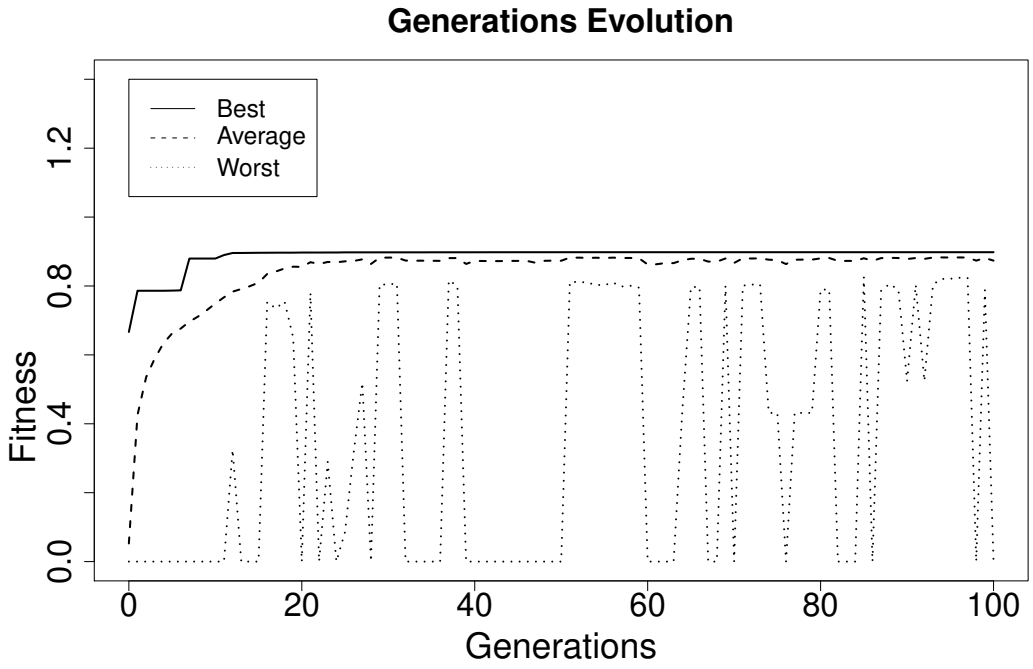
- Función de Fitness

- PROPUESTAS!!!!
- Nolfi-Floreano: $F = V(1 - \sqrt{\Delta v})(1 - i)$

$$W_{r,l} \in [-0.5, 0.5] \quad \text{(Velocidad)}$$
$$V = |W_r| + |W_l| \quad \text{(Máxima Velocidad)}$$
$$\Delta v = |(W_r + 0.5) - (W_l + 0.5)| \quad \text{(Máximo Recto)}$$
$$i \in [0, 1] \quad \text{(Máximo IR)}$$

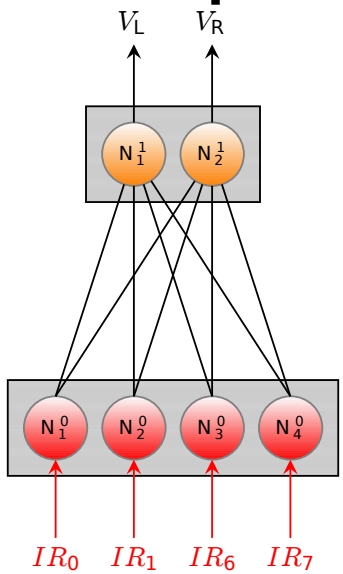
Evitador de Obstáculos

- **100** generaciones
- **100** individuos
- **100** seg. de evaluación
- **Mutación**: $p_m = \mathbf{0.05}$
- **Crossover**: $p_c = \mathbf{1}$
- **Elite**: $e = \mathbf{4}$



IRSIM

ANN: Exp 21

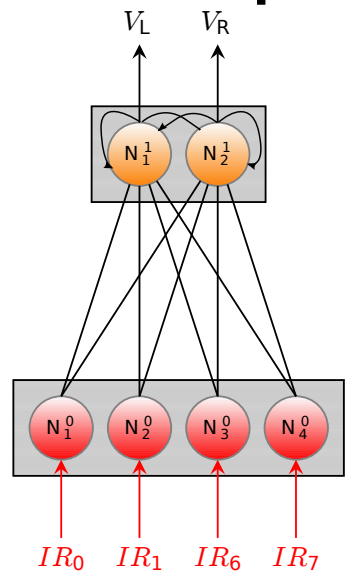


- Identidad $y_i = x_i$
- Sigmoide

$$n_i = \sum_j \omega_{ji} x_i + I_i$$

$$y_i = \frac{1}{1 + e^{-(n_i - \theta_i)}}$$

CTRNN: Exp 24



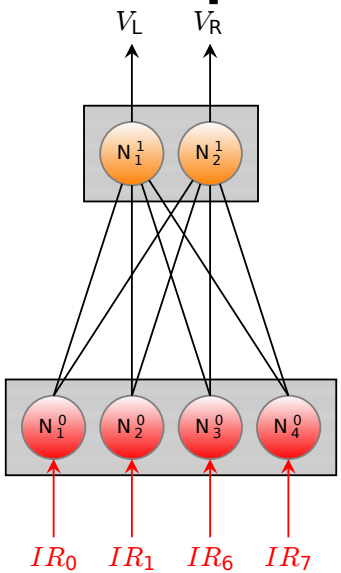
- Identidad $y_i = x_i$
- Sigmoide

$$\tau_i \dot{n}_i = -n_i + \sum_j \omega_{ji} x_i + g_i I_i$$

$$y_i = \frac{1}{1 + e^{-\beta_i (n_i - \theta_i)}}$$

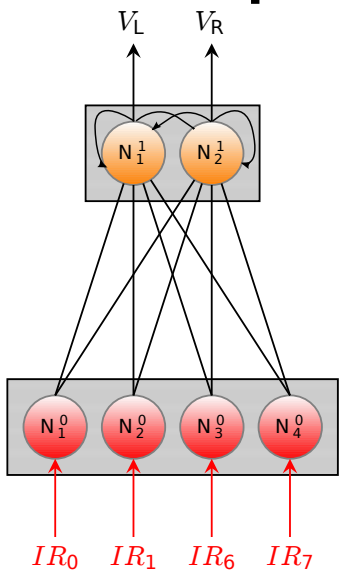
IRSIM

ANN: Exp 21



- Parámetros Sigmoides:
  ω, θ

CTRNN: Exp 24



- Parámetros Sigmoides:
  ω, g, θ, β, τ

ANN: Exp 21

- `experiments/testneuronexp.*`
- `controllers/nndistributedcontroller.*`
- `controllers/layercontroller.*`

CTRNN: Exp 24

- `experiments/ctrnnexp.*`
- `controllers/ctrnndistributedcontroller.*`
- `controllers/ctrnnlayercontroller.*`

Fichero Configuración

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%% MORPHOLOGY %%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
PROX. SENSORS (8 sensors: 0 OFF, 1 ON) = 1 1 0 0 0 0 1 1
CONTACT SENSORS (8 sensors: 0 OFF, 1 ON) = 1 1 1 1 1 1 1 1
LIGHT SENSORS (8 sensors: 0 OFF, 1 ON) = 1 1 1 1 1 1 1 1
BLUE LIGHT SENSORS (8 sensors: 0 OFF, 1 ON) = 1 1 1 1 1 1 1 1
RED LIGHT SENSORS (8 sensors: 0 OFF, 1 ON) = 1 1 1 1 1 1 1 1
GROUND SENSORS (3 sensors: 0 OFF, 1 ON) = 1 1 1
```

Fichero Configuración

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%% GENETIC%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
CHROMOSOME LENGTH = 10
POPULATION SIZE = 20
NUMBER OF GENERATIONS = 101
EVALUATION TIME = 100
DO CROSSOVER ( 0 No, 1 Yes ) = 1
NUMBER OF CROSSOVERS ( Always 1 ) = 1
CROSSOVER DISTANCE ( Always 1 ) = 1
MUTATION RATE = 0.02
NUMBER OF ELITES = 1
FITNESS FUNCTION = 1
SAMPLES PER CHORMOSOME = 1
RANDOM POS/ORIEN (0 NO, 1 YES) = 0
RANDOM INIT AREA X = 1.2
RANDOM INIT AREA Y = 1.2
```

Fichero Configuración

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%% NEURAL%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
WEIGTH UPPER BOUND = 5.0
WEIGTH LOWER BOUND = -5.0
NUMBER OF LAYERS= 2
SENSOR TO LAYER 0 ( NONE 0, C. 1, P. 2, L. 3, BAT. 4, GM 5, G 6,
BL 7, RL 8, BBAT 9, RBAT 10) = 2
SENSOR TO LAYER 0 ( NONE 0, C. 1, P. 2, L. 3, BAT. 4, GM 5, G 6,
BL 7, RL 8, BBAT 9, RBAT 10) = 0
ACTIVATION FUNCTION LAYER 0 ( 0 IDENTITY, 1 SIGMOID, 2 STEP, 3
LINEAR, 4 PROGRAM ) = 0
ACTIVATION FUNCTION LAYER 1 ( 0 IDENTITY, 1 SIGMOID, 2 STEP, 3
LINEAR, 4 PROGRAM ) = 1
NUMBER OF OUTPUTs LAYER 0 = 4
NUMBER OF OUTPUTs LAYER 1 = 2
RELATION LAYER 0 = 0 1
RELATION LAYER 1 = 0 0
```

ANN: Exp 21

- **Evolución**
  - ./irsim -E 21 -p <PARAM_FILE> -e
- **Ejecución**
  - ./irsim -E 21 -p <PARAM_FILE> -c <CHROM_FILE>

CTRNN: Exp 24

- **Evolución**
  - ./irsim -E 24 -p <PARAM_FILE> -e
- **Ejecución**
  - ./irsim -E 24 -p <PARAM_FILE> -c <CHROM_FILE>

Datos

- **Evolución**:
  - En el directorio `geneticDatatFiles`
    - `bestX.log`: El mejor individuo de la generación X
    - `currentbest`: El mejor individuo de todo el proceso
    - `fitness.log`: Histórico de la evolución de la fitness
    - `generationX.log`: Fichero con todos los individuos de la generación X
    - `maxgeneration`: La última generación ejecutada
- **Ejecución**
  - En el directorio `outputFiles`
    - `layerXoutput`: Fichero con el tiempo, entradas sensoriales, parámetros de la red (pesos, sesgos, ganancias, ...) y salidas de cada capa
    - `robotPosition`: Fichero con el tiempo, coordenadaX, coordenadaY y Orientación del robot
    - `robotWheels`: Fichero con el tiempo, velocidad de la rueda izquierda y velocidad de la rueda derecha

Fitness

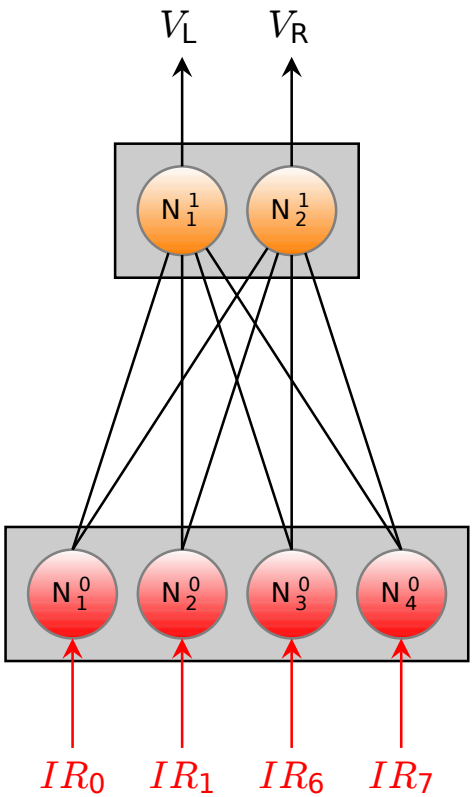
- **0**: None
- **1**: Avoid experiments
  `fitnessfunctions/avoidcollisionsfitnessfunction.*`
- **2**: Garbage experiments
  `fitnessfunctions/garbagefitnessfunction.*`
- **4**: **VUESTRA FITNESS**
  `fitnessfunctions/irifitnessfunction.*`
- **5**: Light Experiments
  `fitnessfunctions/lightfitnessfunction.*`

Varios

- **Reiniciar generación**: Modificar variable `g_bRestartEvolution`. Reinicia la simulación desde la que indique el fichero `maxgeneration`
- **Tipo Mutación**:
  - **Aleatoria**: En el fichero `populations/standardgapopulation.cpp`, lineas 302 y 327:
    - `fGene = Random2::nextDouble();`
  - **Gausiana** sobre el valor del gen actual: En el fichero `populations/standardgapopulation.cpp`, lineas 302 y 327:
    - `fGene = fGene + Random2::nextGaussian(0,0.1);`

Ejemplo evitación de obstáculos

ANN: Exp 21



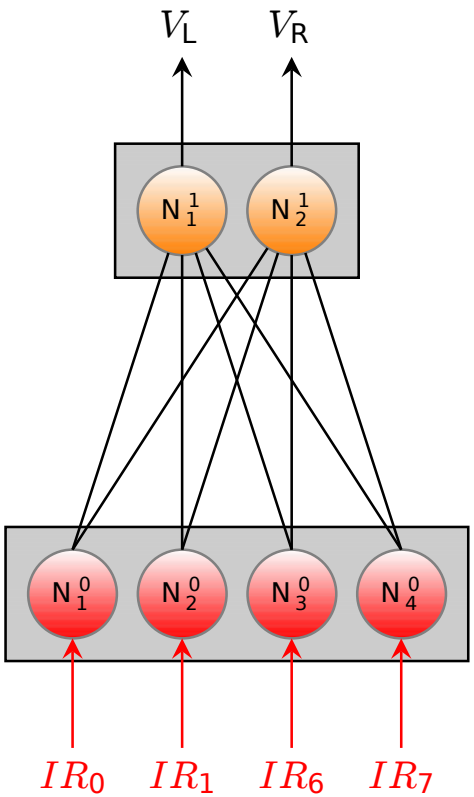
- **Exp1**:
  - Cromosoma:

- Nolfi-Floreano:

$$F = V(1 - \sqrt{\Delta v})(1 - i)$$

Ejemplo evitación de obstáculos

ANN: Exp 21



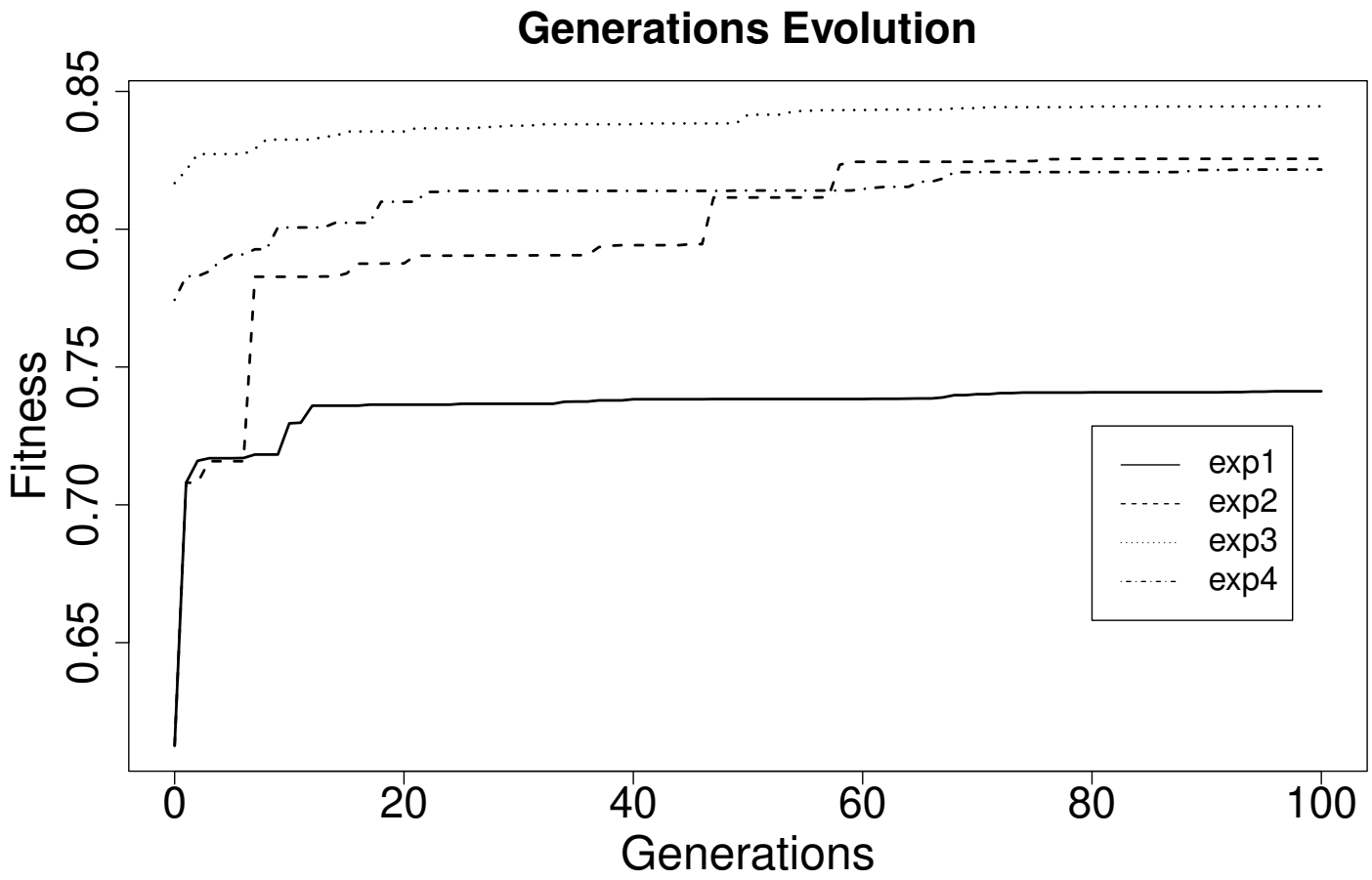
- Nolfi-Floreano:
  $F = V(1 - \sqrt{\Delta v})(1 - i)$

- **Exp1**:
  - Cromosoma: 10
  - Población: 20
  - Mutación: 2 %
  - Tiempo eval: 100 s.
  - Elites: 2
- **Exp2**:
  - Mutación: 5 %
- **Exp3**:
  - Población: 50
  - Mutación: 2 %
- **Exp4**:
  - Obstáculos

Ejemplo evitación de obstáculos

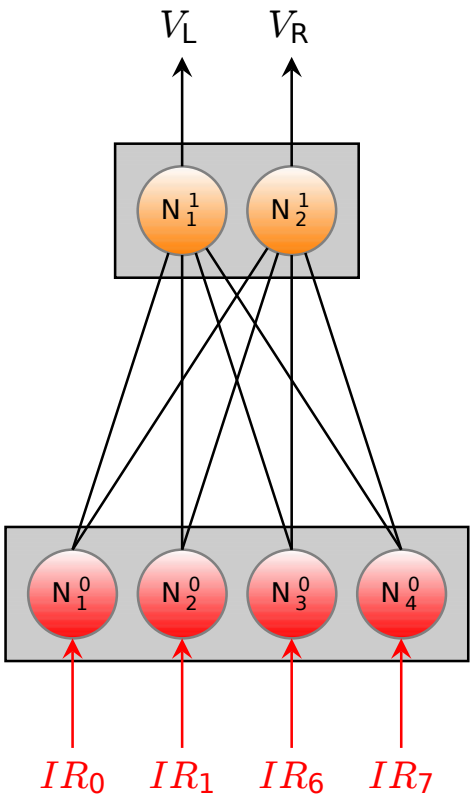
ANN: Exp 21 - 100 generaciones

- **Exp1**: 0.741 **Exp2**: 0.825 **Exp3**: 0.844 **Exp4**: 0.821



Ejemplo evitación de obstáculos

CTRNN: Exp 24



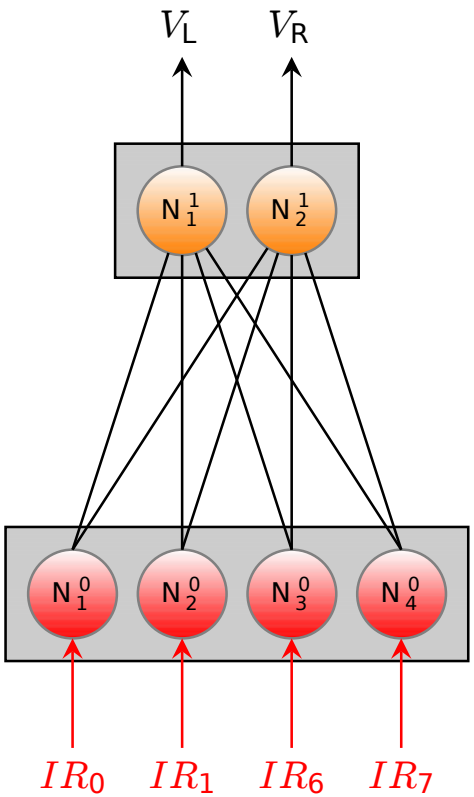
- **Exp1**:
  - Cromosoma:

- Nolfi-Floreano:

$$F = V(1 - \sqrt{\Delta v})(1 - i)$$

Ejemplo evitación de obstáculos

CTRNN: Exp 24



- Nolfi-Floreano:

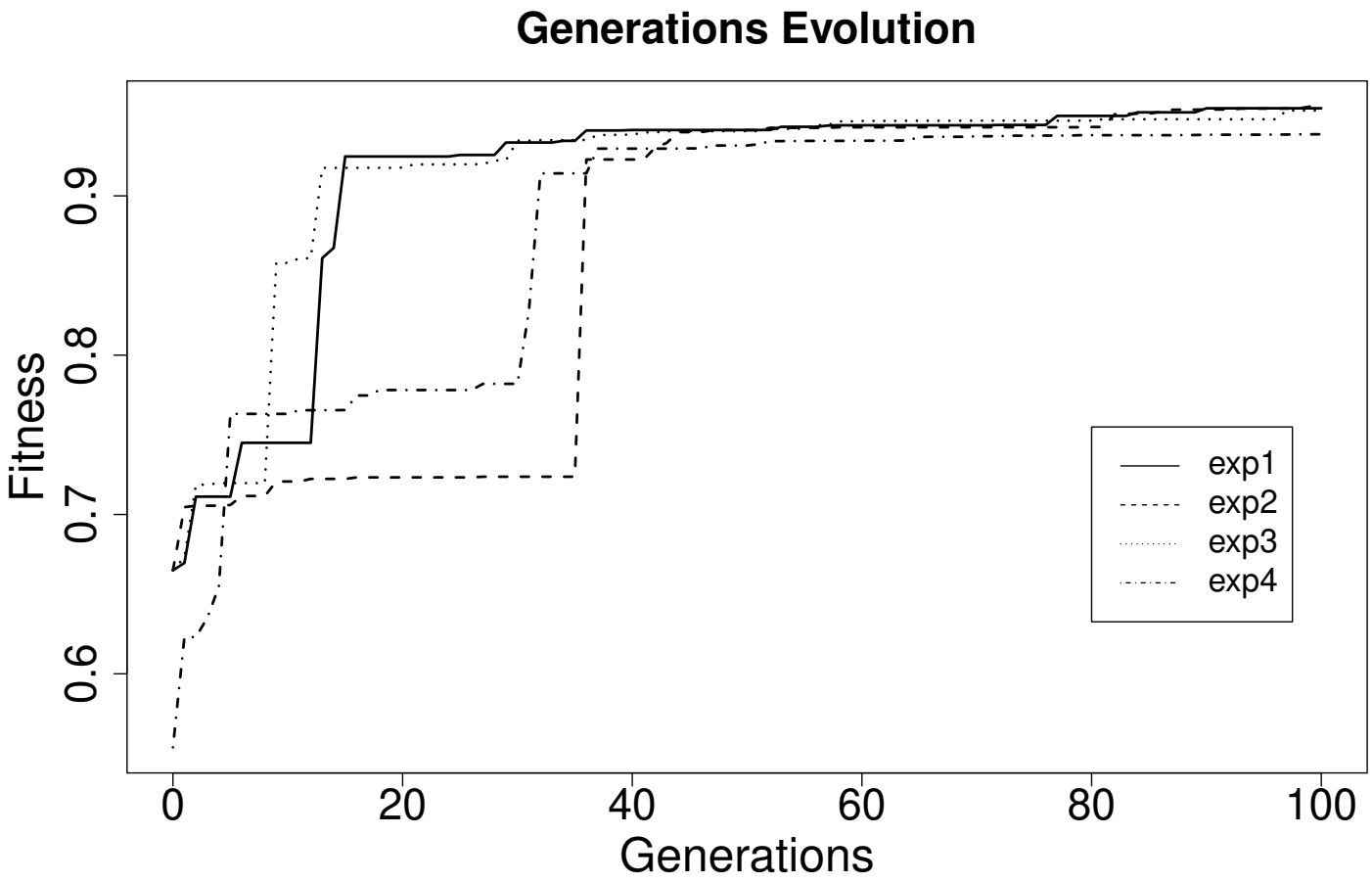
$$F = V(1 - \sqrt{\Delta v})(1 - i)$$

- **Exp1**:
  - Cromosoma: 14
  - Población: 20
  - Mutación: 2 %
  - Tiempo eval: 100 s.
  - Elites: 2
- **Exp2**:
  - Mutación: 5 %
- **Exp3**:
  - Población: 50
  - Mutación: 2 %
- **Exp4**:
  - Obstáculos

Ejemplo evitación de obstáculos

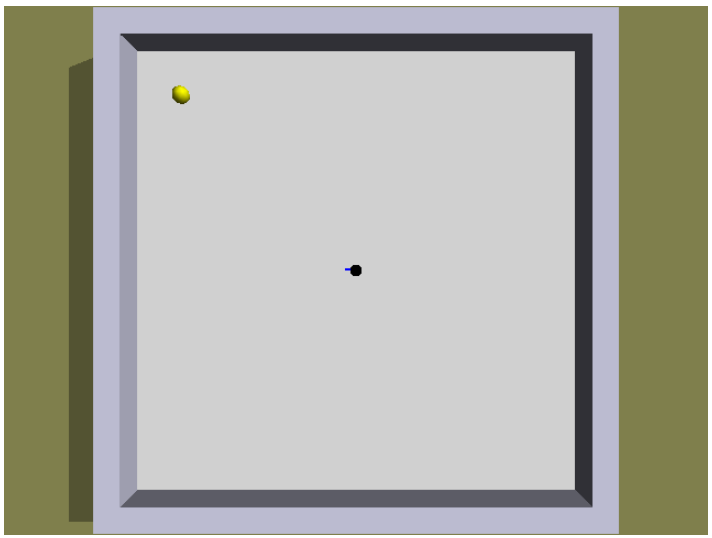
CTRNN: Exp 24

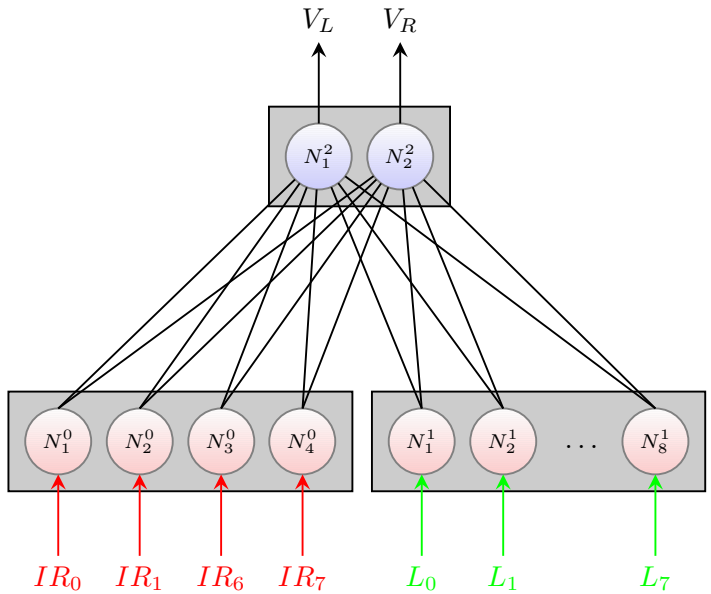
- **Exp1**: 0.954 **Exp2**: 0.956 **Exp3**: 0.953 **Exp4**: 0.938



Navegar hacia una luz

ANN: Exp 1

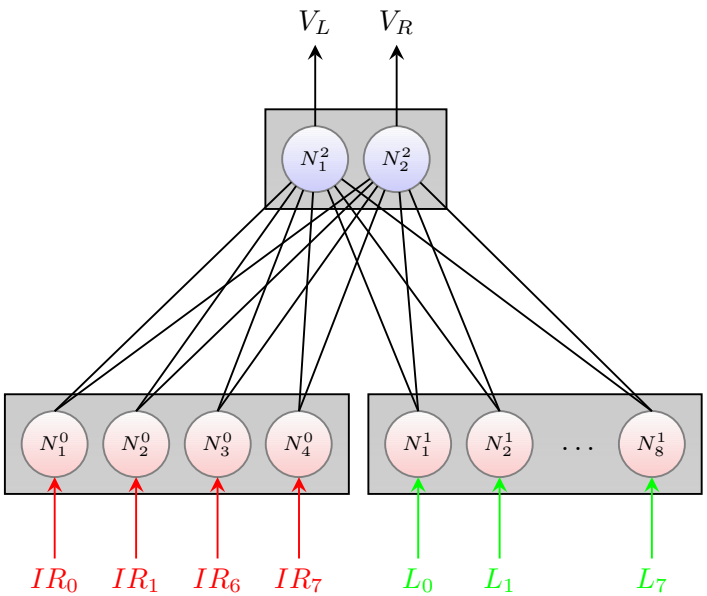




$$F = \frac{\sum_{i=0}^{N_{steps}} V \cdot (1 - \sqrt{\Delta v}) \cdot (max\{L_i\})}{N_{steps}} \cdot \left(1 - min\left\{\frac{N_{coll}, 10}{10}\right\}\right)$$

Navegar hacia una luz

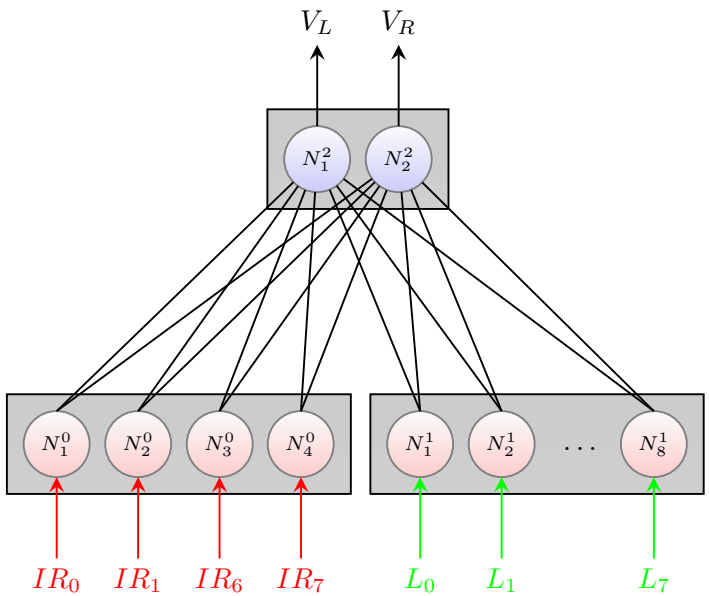
ANN: Exp 1



- Cromosoma:

Navegar hacia una luz

ANN: Exp 1

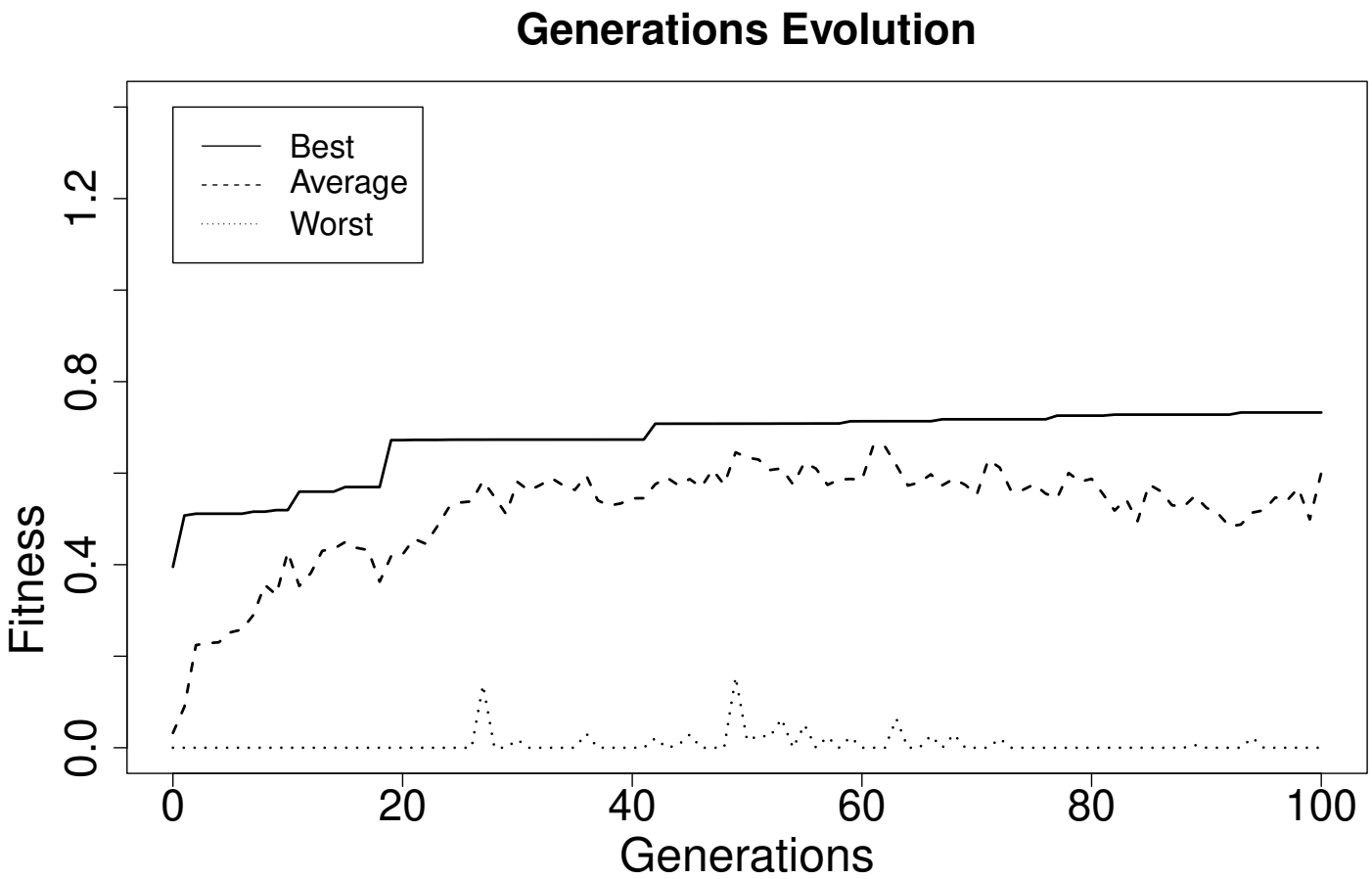


- Cromosoma: 26
- Población: 50
- Mutación: 5 %
- Tiempo eval: 400 s.
- Elites: 4

$$F = \frac{\sum_{i=0}^{N_{steps}} V \cdot (1 - \sqrt{\Delta v}) \cdot (max\{L_i\})}{N_{steps}} \cdot \left(1 - min\left\{\frac{N_{coll}, 10}{10}\right\}\right)$$

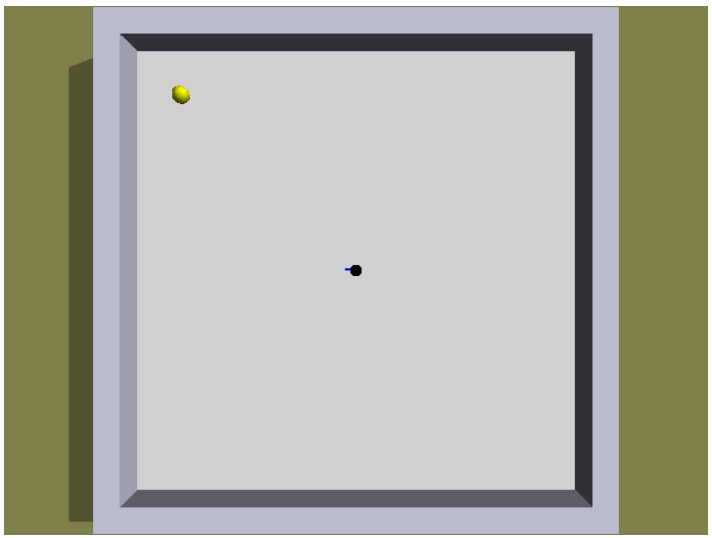
Navegar hacia una luz

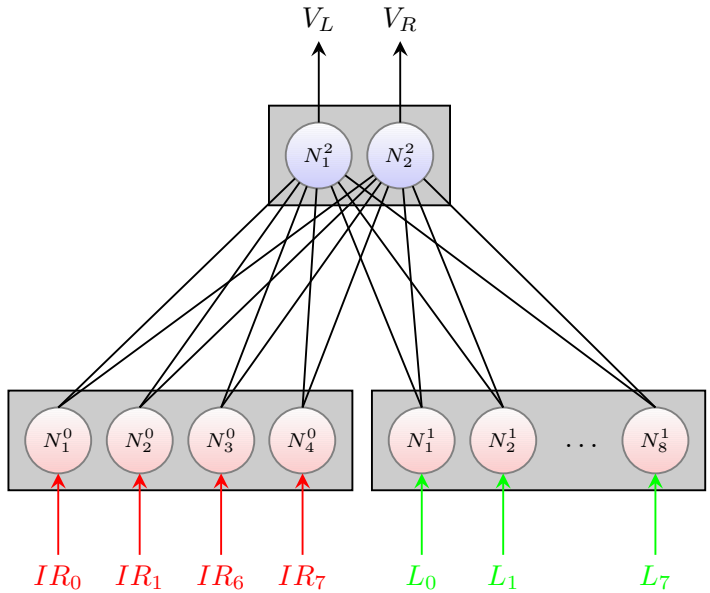
ANN: Exp 1



Navegar hacia una luz

CTRNN: Exp 1

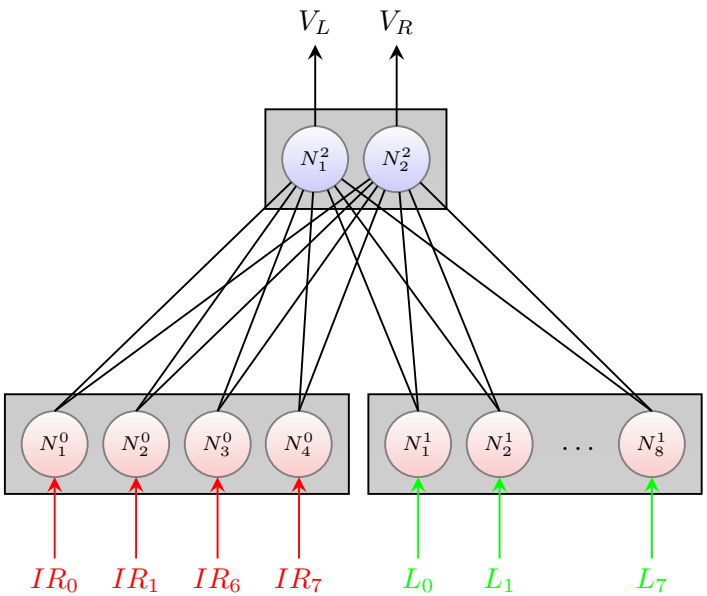




$$F = \frac{\sum_{i=0}^{N_{steps}} V \cdot (1 - \sqrt{\Delta v}) \cdot (max\{L_i\})}{N_{steps}} \cdot \left(1 - min\left\{\frac{N_{coll}, 10}{10}\right\}\right)$$

Navegar hacia una luz

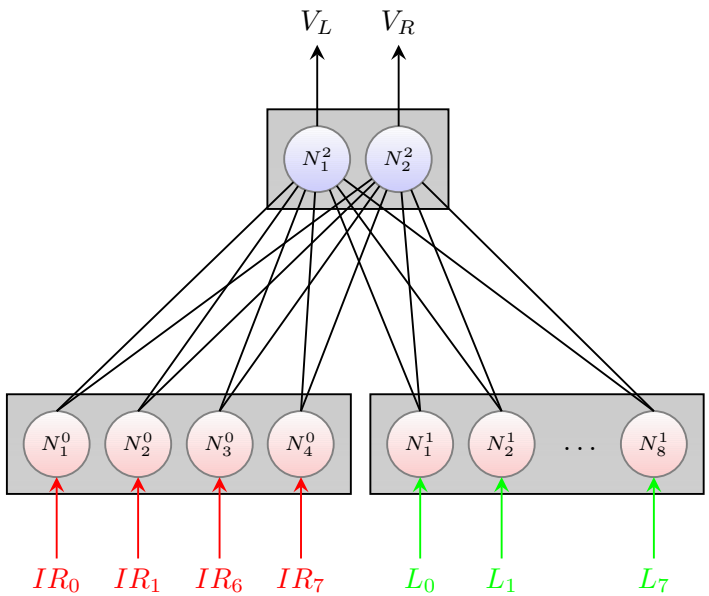
CTRNN: Exp 1



- Cromosoma:

Navegar hacia una luz

CTRNN: Exp 1

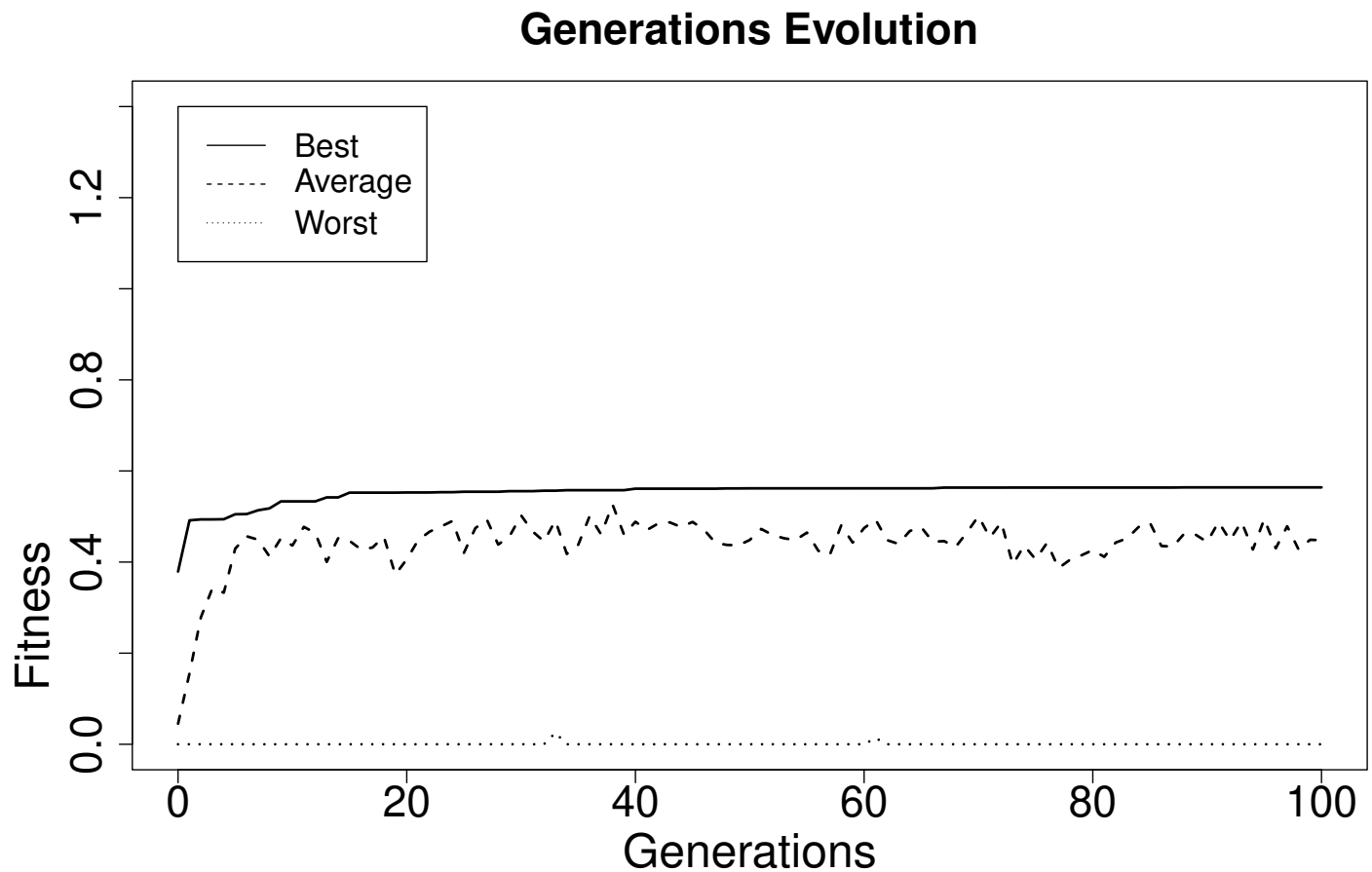


- Cromosoma: 30
- Población: 50
- Mutación: 2 %
- Tiempo eval: 400 s.
- Elites: 4

$$F = \frac{\sum_{i=0}^{N_{steps}} V \cdot (1 - \sqrt{\Delta v}) \cdot (max\{L_i\})}{N_{steps}} \cdot \left(1 - min\left\{\frac{N_{coll}, 10}{10}\right\}\right)$$

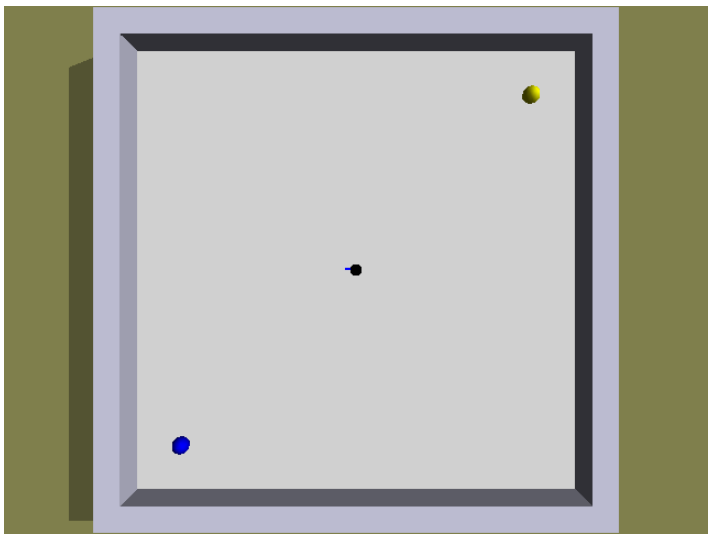
Navegar hacia una luz

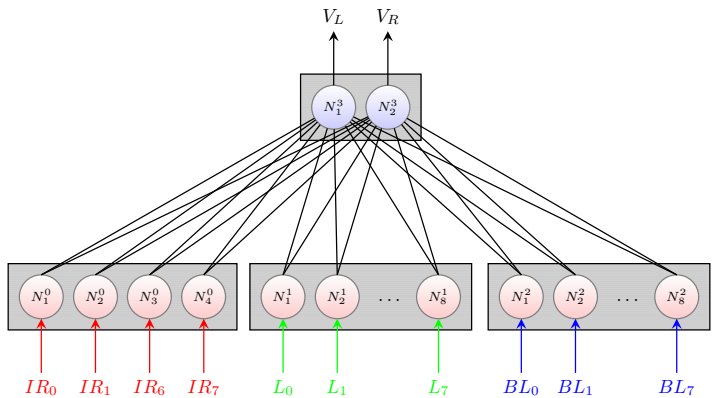
CTRNN: Exp 1



Oscilación entre luces

ANN: Exp 2

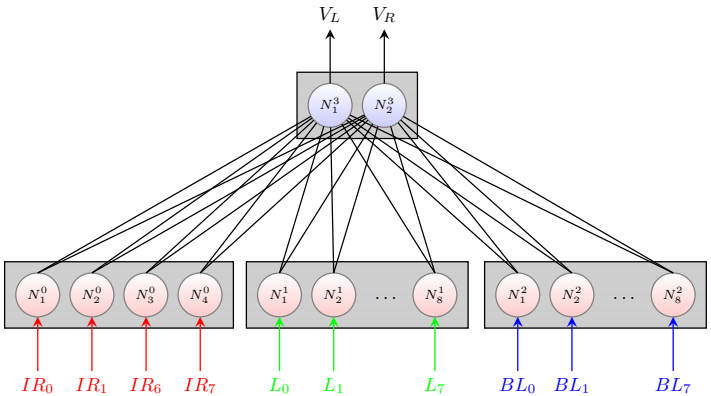




$$F = \frac{\sum_{i=0}^{N_{steps}} \left[\frac{1}{4} V(1 - \sqrt{\Delta v}) + \frac{3}{4} \left[BL_{on}(BL_0 + BL_7) + BL_{off}(L_0 + L_7) \right] \right]}{N_{steps}} \left(1 - min \left\{ \frac{N_{coll}, 10}{10} \right\} \right)$$

Oscilación entre luces

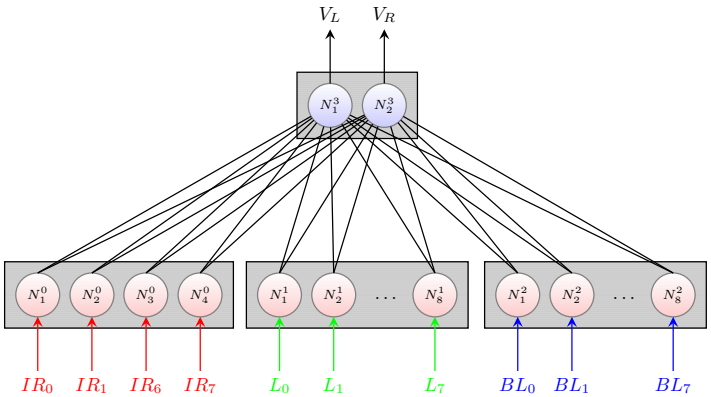
ANN: Exp 2



- Cromosoma:

Oscilación entre luces

ANN: Exp 2

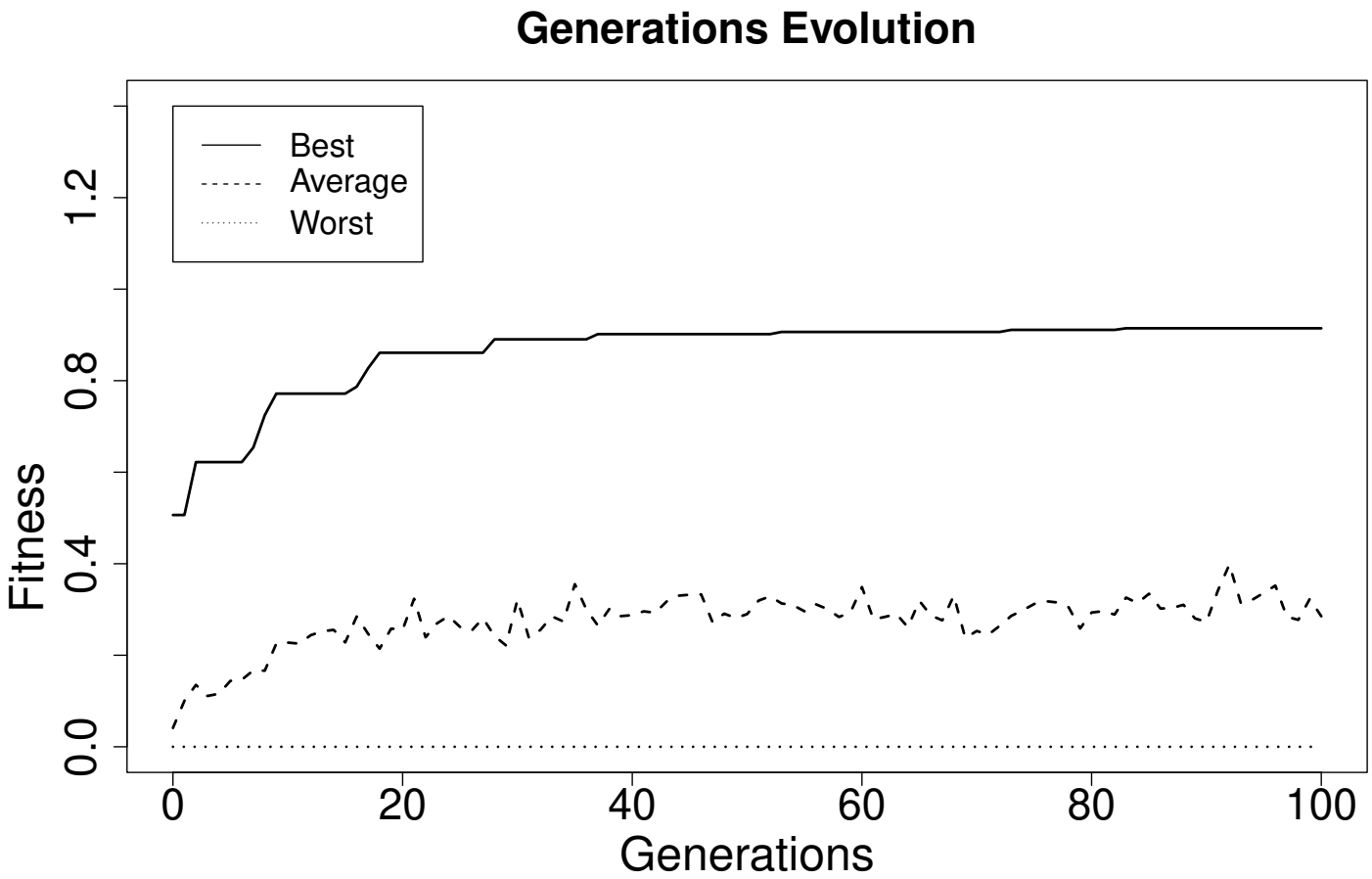


- Cromosoma: 42
- Población: 100
- Mutación: 20 %
- Tiempo eval: 400 s.
- Elites: 6

$$F = \frac{\sum_{i=0}^{N_{steps}} \left[\frac{1}{4} V(1 - \sqrt{\Delta v}) + \frac{3}{4} \left[BL_{on}(BL_0 + BL_7) + BL_{off}(L_0 + L_7) \right] \right]}{N_{steps}} \left(1 - min \left\{ \frac{N_{coll}, 10}{10} \right\} \right)$$

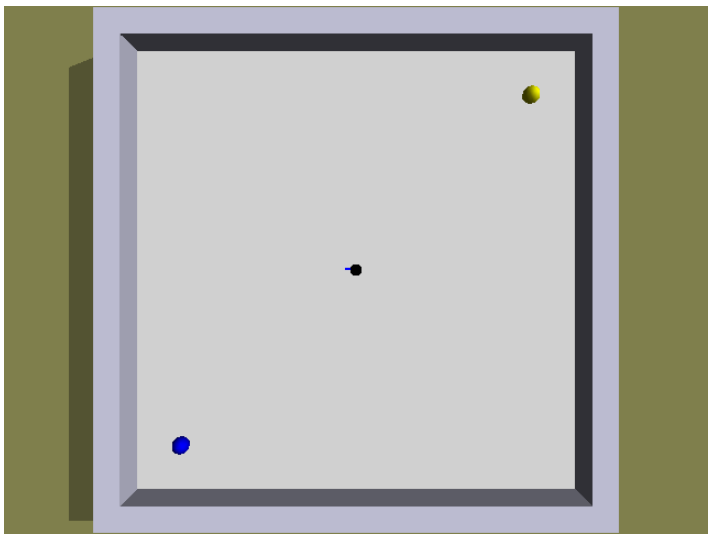
Oscilación entre luces

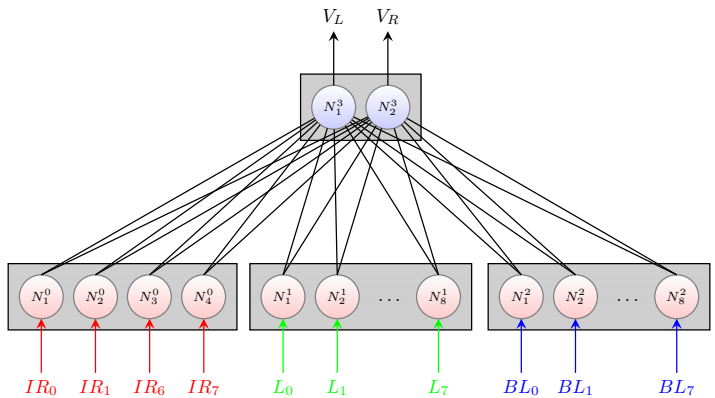
ANN: Exp 2



Oscilación entre luces

CTRNN: Exp 2

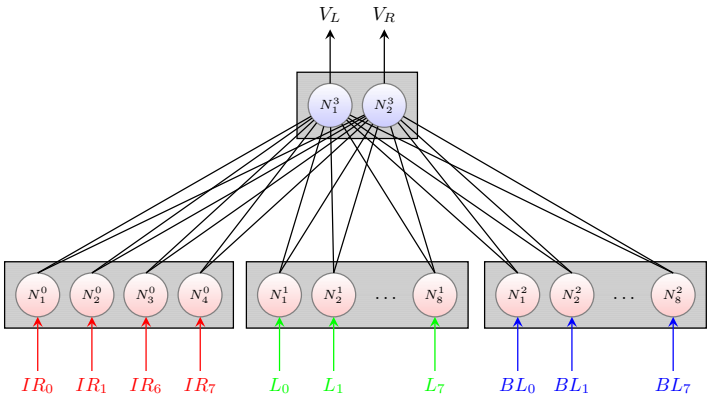




$$F = \frac{\sum_{i=0}^{N_{steps}} \left[\frac{1}{4} V(1 - \sqrt{\Delta v}) + \frac{3}{4} \left[BL_{on}(BL_0 + BL_7) + BL_{off}(L_0 + L_7) \right] \right]}{N_{steps}} \left(1 - min \left\{ \frac{N_{coll}, 10}{10} \right\} \right)$$

Oscilación entre luces

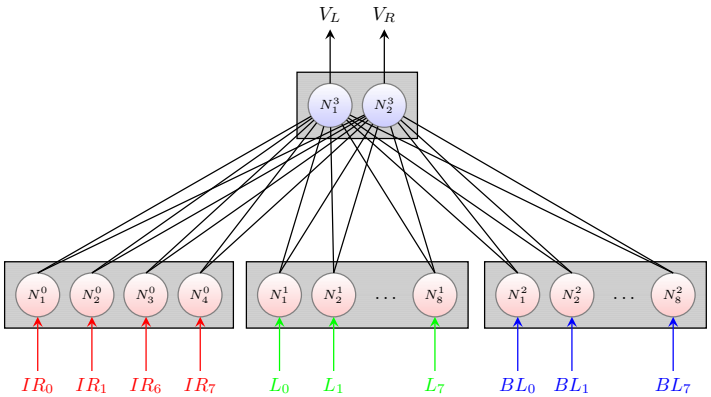
CTRNN: Exp 2



- Cromosoma:

Oscilación entre luces

CTRNN: Exp 2

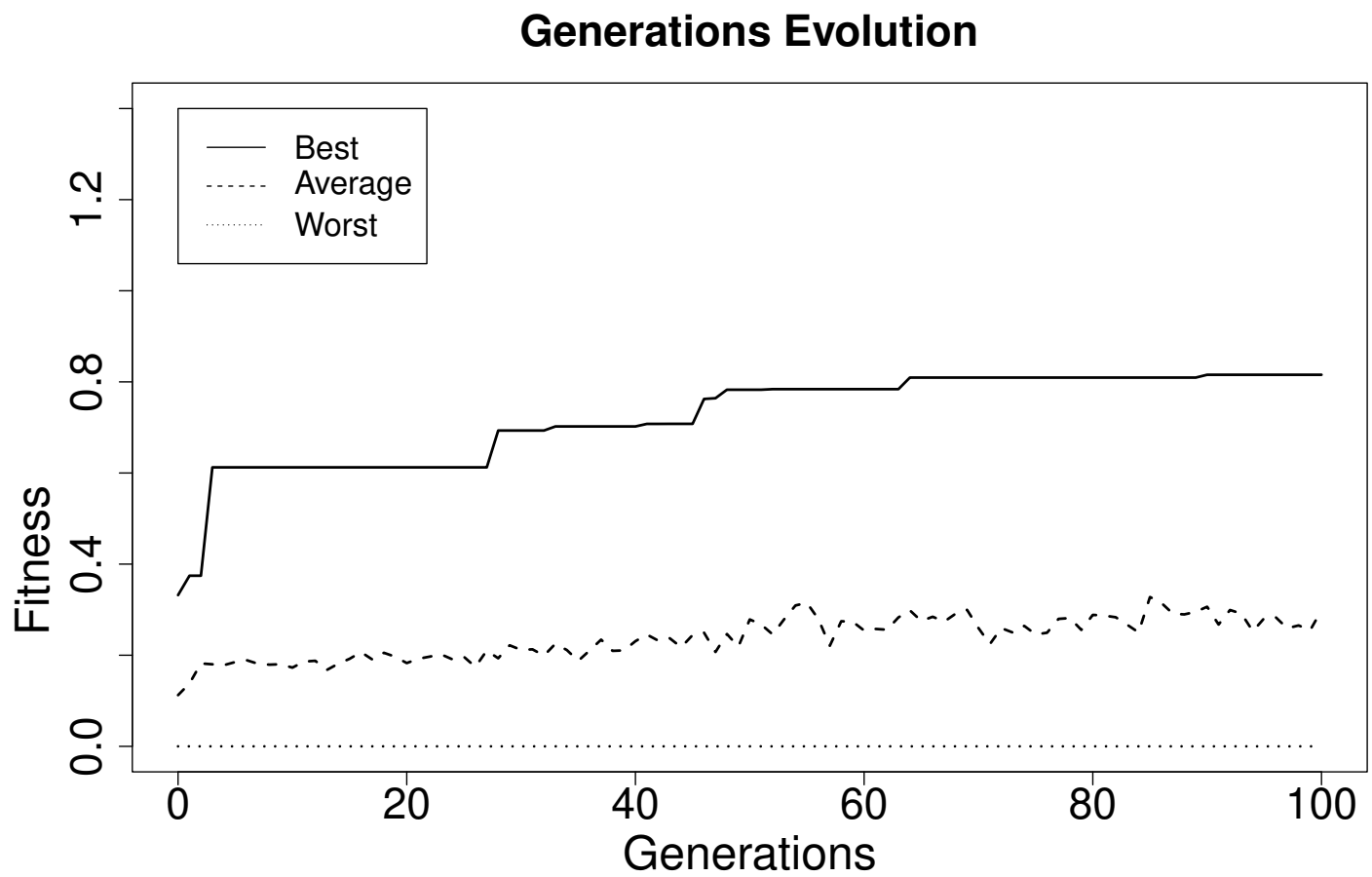


- Cromosoma: 46
- Población: 100
- Mutación: 20 %
- Tiempo eval: 400 s.
- Elites: 6

$$F = \frac{\sum_{i=0}^{N_{steps}} \left[\frac{1}{4} V(1 - \sqrt{\Delta v}) + \frac{3}{4} \left[BL_{on}(BL_0 + BL_7) + BL_{off}(L_0 + L_7) \right] \right]}{N_{steps}} \left(1 - min \left\{ \frac{N_{coll}, 10}{10} \right\} \right)$$

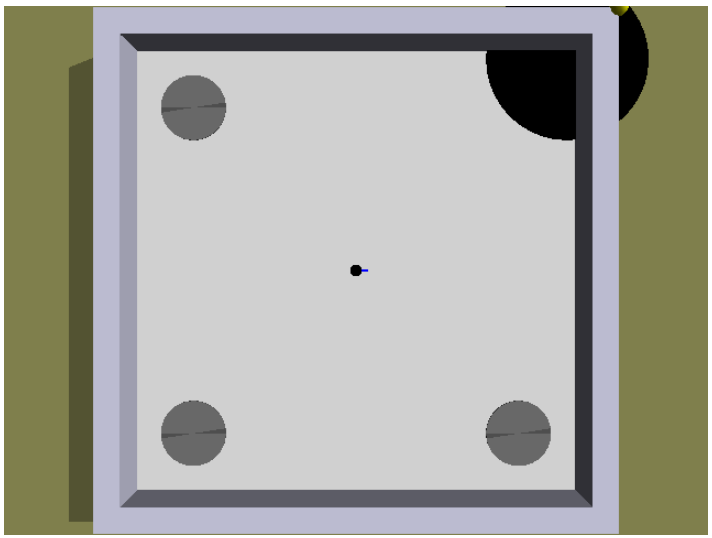
Oscilación entre luces

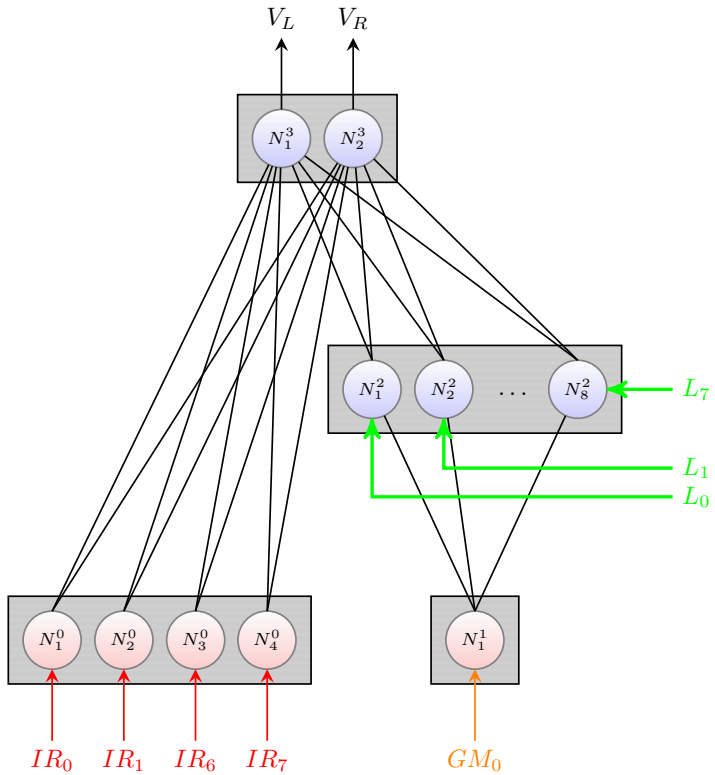
CTRNN: Exp 2



Recolección

ANN: Exp 1

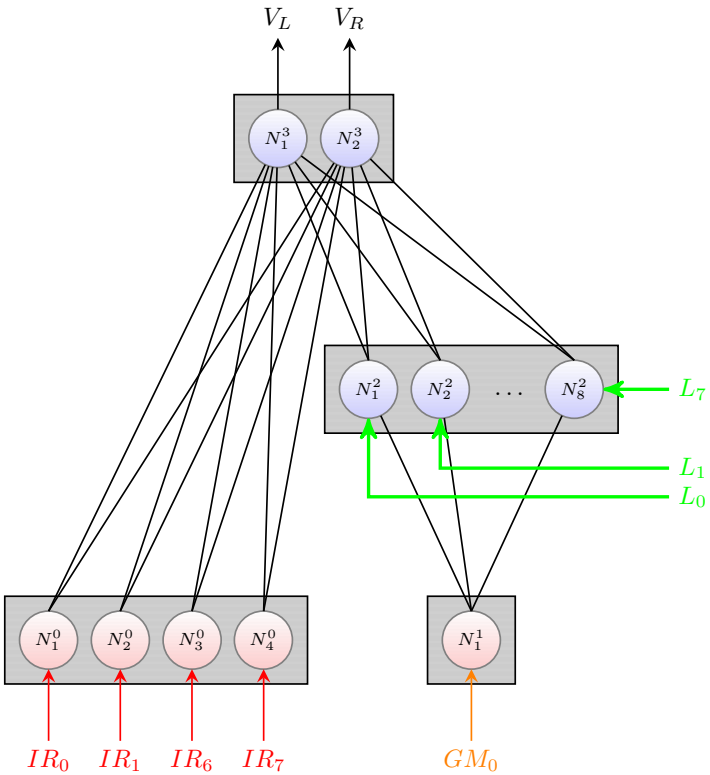




$$F = \frac{\sum_{i=0}^{N_{steps}} GM_{off}\left[V(1-\sqrt{\Delta v})(1-max\{I_i\})\right] + GM_{on}\left(max\{L_i\}\right)}{N_{steps}}$$

Recolección

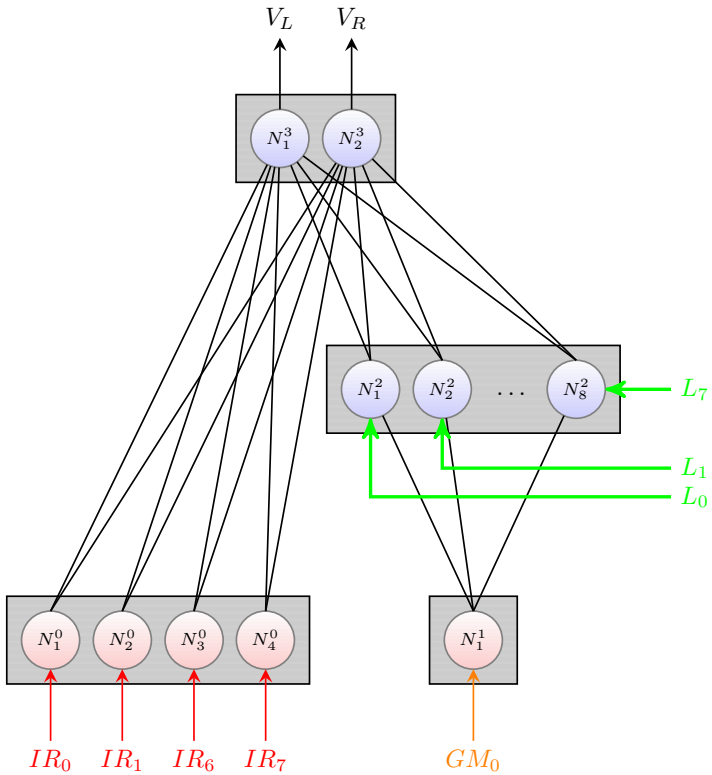
ANN: Exp 1



- Cromosoma:

Recolección

ANN: Exp 1

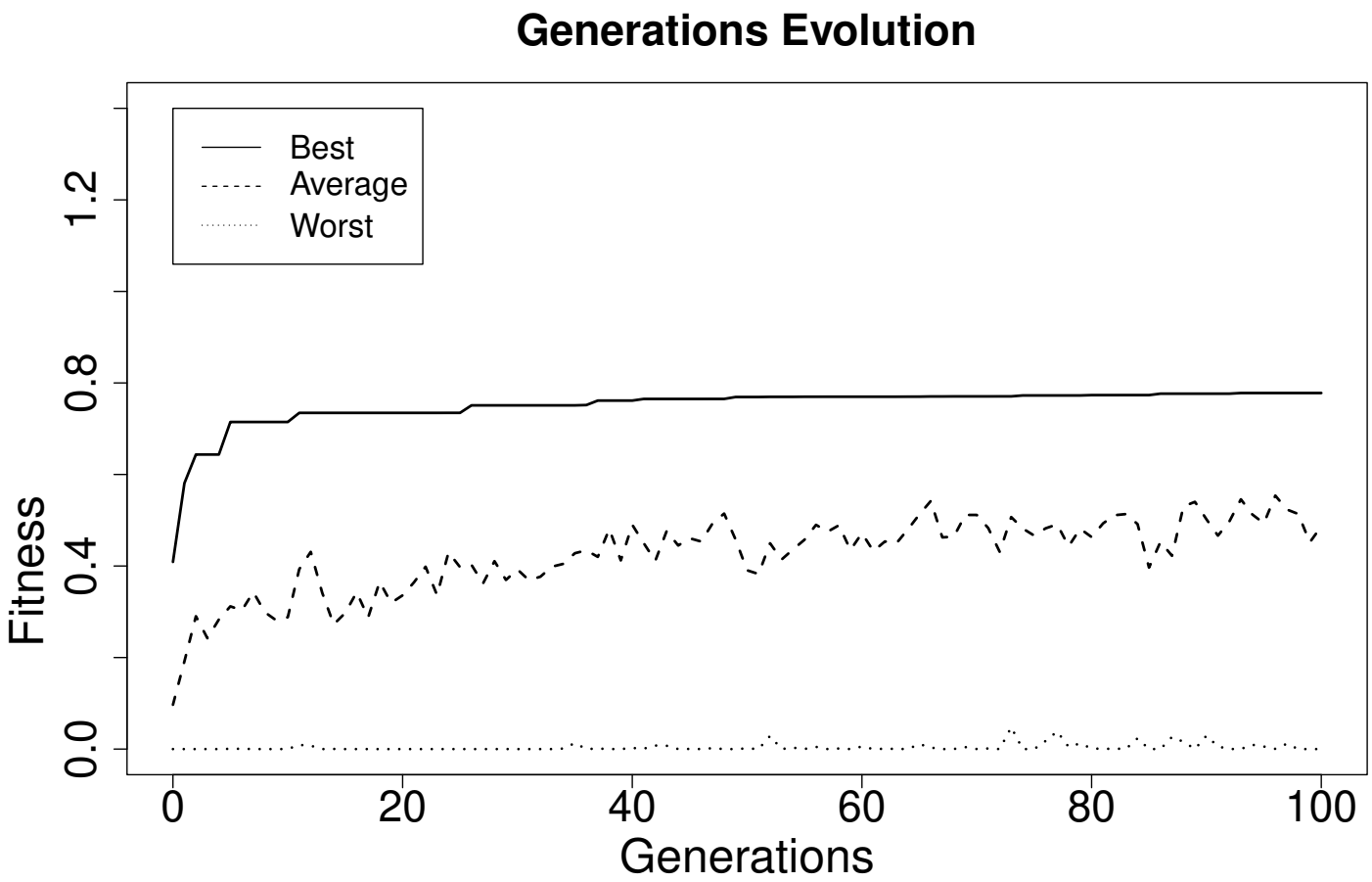


- Cromosoma: 42
- Población: 50
- Mutación: 5 %
- Tiempo eval: 300 s.
- Elites: 4

$$F = \frac{\sum_{i=0}^{N_{steps}} GM_{off}\left[V(1-\sqrt{\Delta v})(1-max\{I_i\})\right] + GM_{on}\left(max\{L_i\}\right)}{N_{steps}}$$

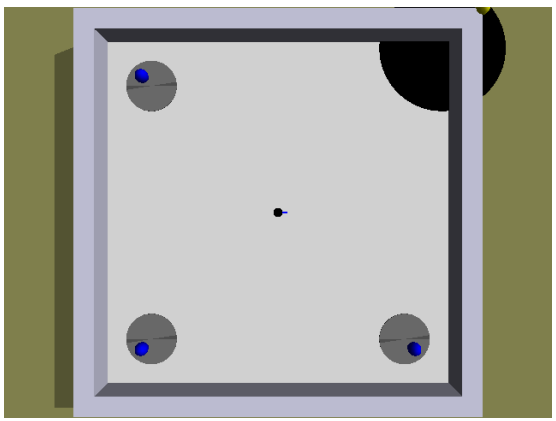
Recolección

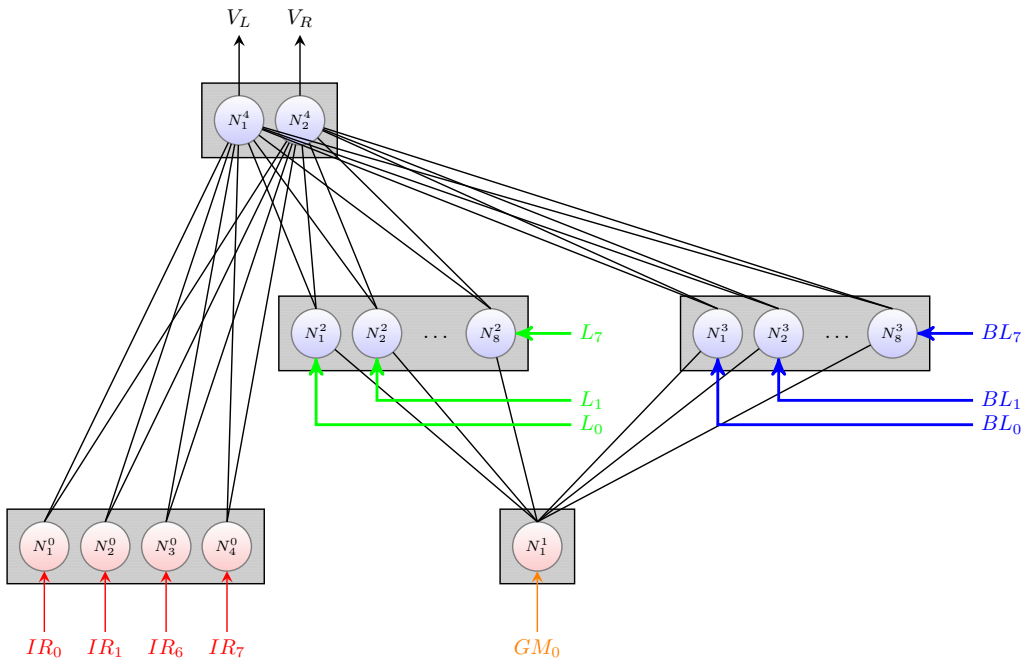
ANN: Exp 1



Recolección

ANN: Exp 2

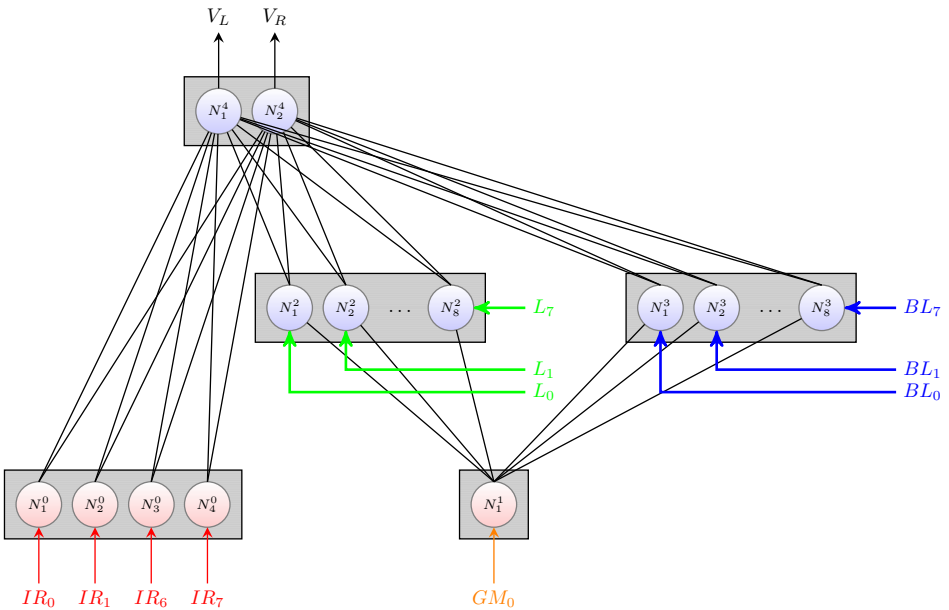




$$F = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7) \right]}{N_{steps}} \left(1 - min \left\{ \frac{N_{coll}, 10}{10} \right\} \right)$$

Recolección

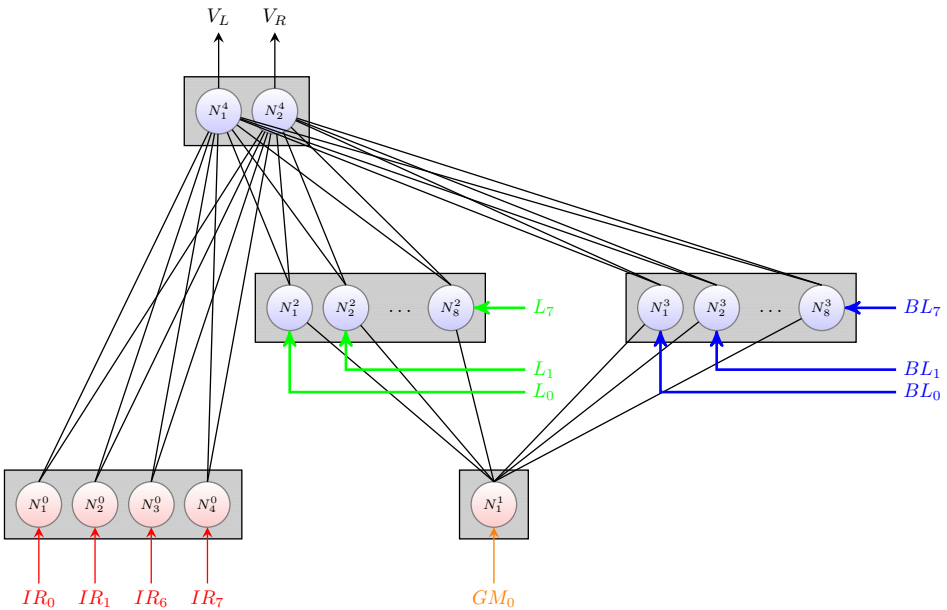
ANN: Exp 2



- Cromosoma:

Recolección

ANN: Exp 2

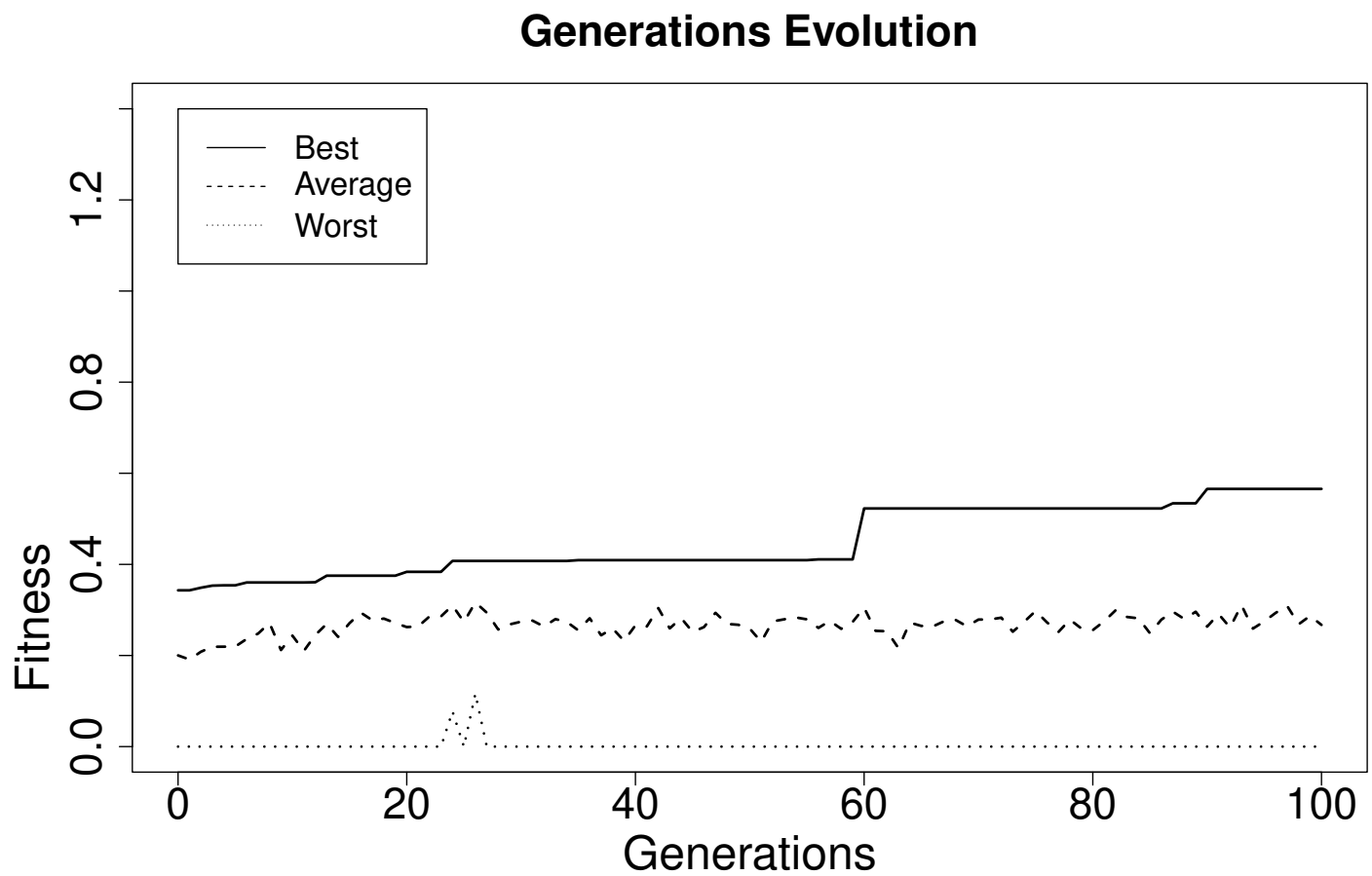


- Cromosoma: 74
- Población: 50
- Mutación: 5 %
- Tiempo eval: 300 s.
- Elites: 6

$$F = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7) \right]}{N_{steps}} \left(1 - min \left\{ \frac{N_{coll}, 10}{10} \right\} \right)$$

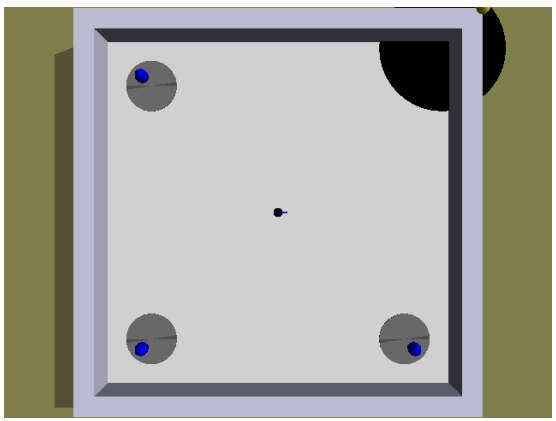
Recolección

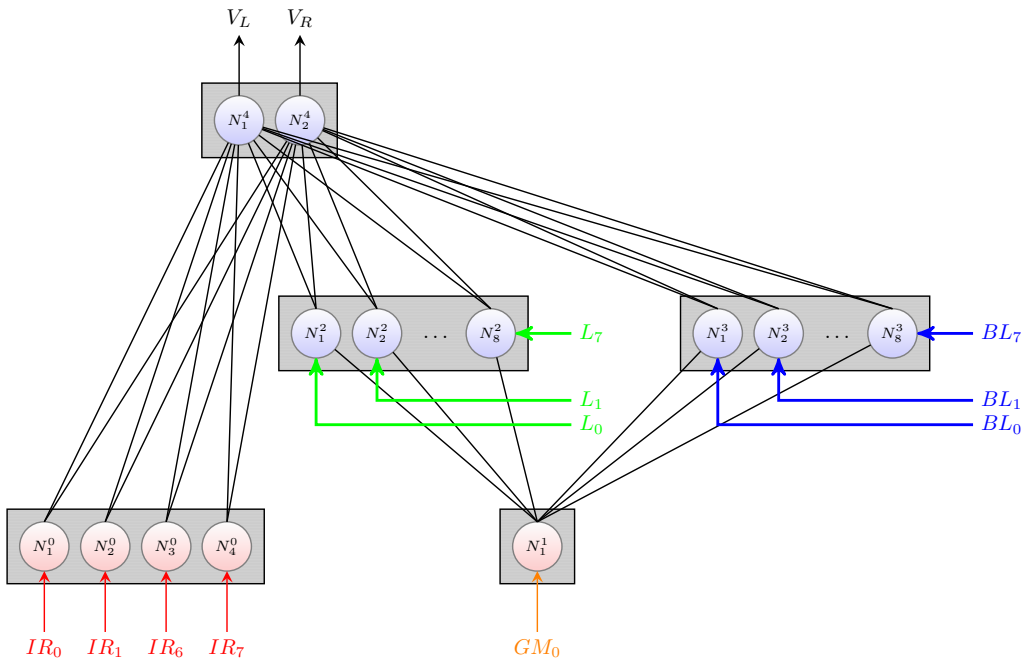
ANN: Exp 2



Recolección

ANN: Exp 3

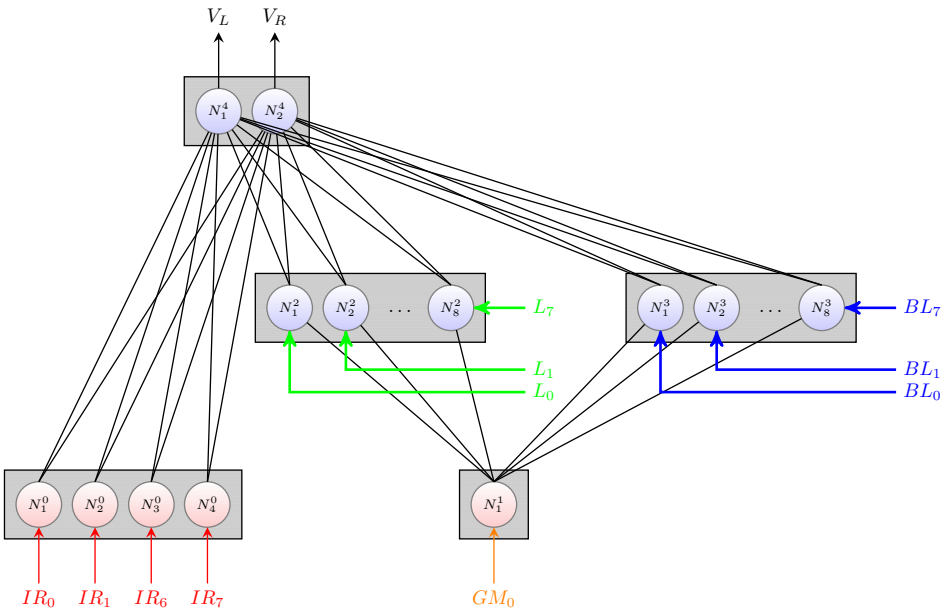




$$F = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7) \right]}{N_{steps}} \left(1 - min \left\{ \frac{N_{coll}, 10}{10} \right\} \right) \left(\frac{F_{obj}}{20} \right)$$

Recolección

ANN: Exp 3

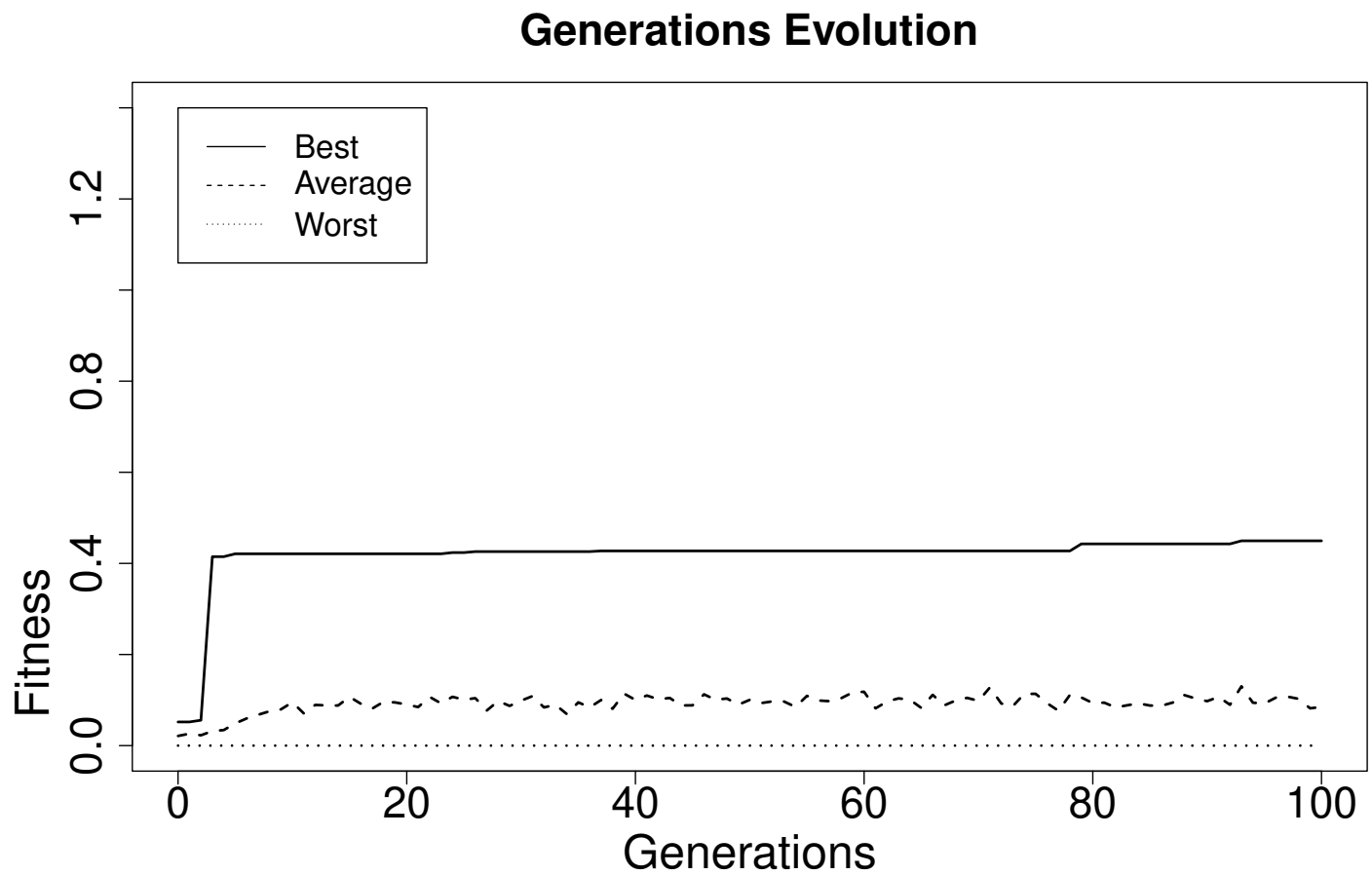


- Cromosoma: 74
- Población: 50
- Mutación: 5 %
- Tiempo eval: 300 s.
- Elites: 6

$$F = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7) \right]}{N_{steps}} \left(1 - min \left\{ \frac{N_{coll}, 10}{10} \right\} \right) \left(\frac{F_{obj}}{20} \right)$$

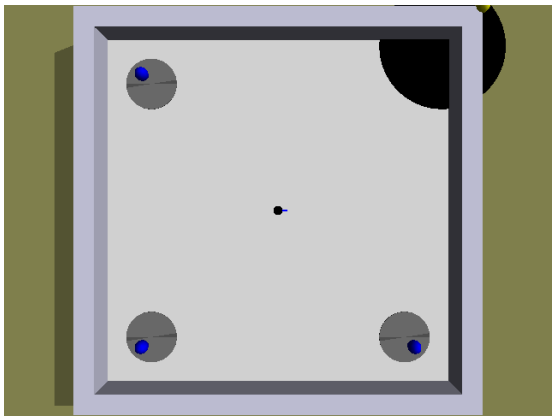
Recolección

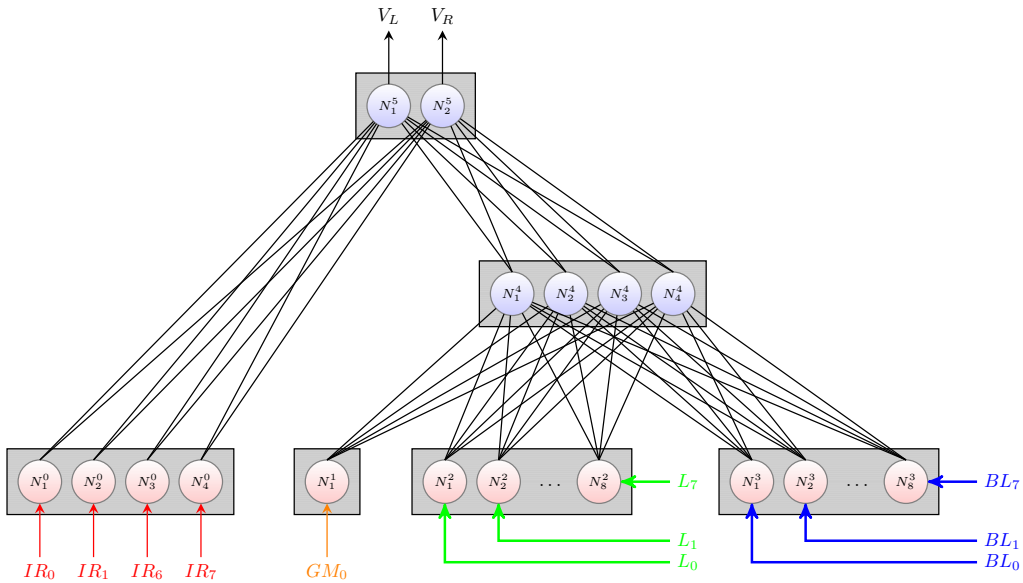
ANN: Exp 3



Recolección

ANN: Exp 4

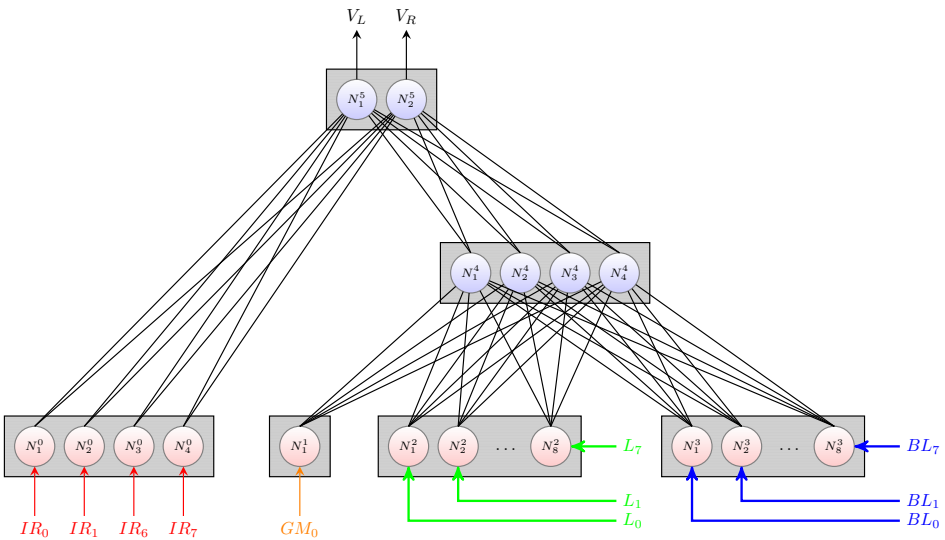




$$F = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7) \right]}{N_{steps}} \left(1 - min \left\{ \frac{N_{coll}, 10}{10} \right\} \right) \left(\frac{F_{obj}}{20} \right)$$

Recolección

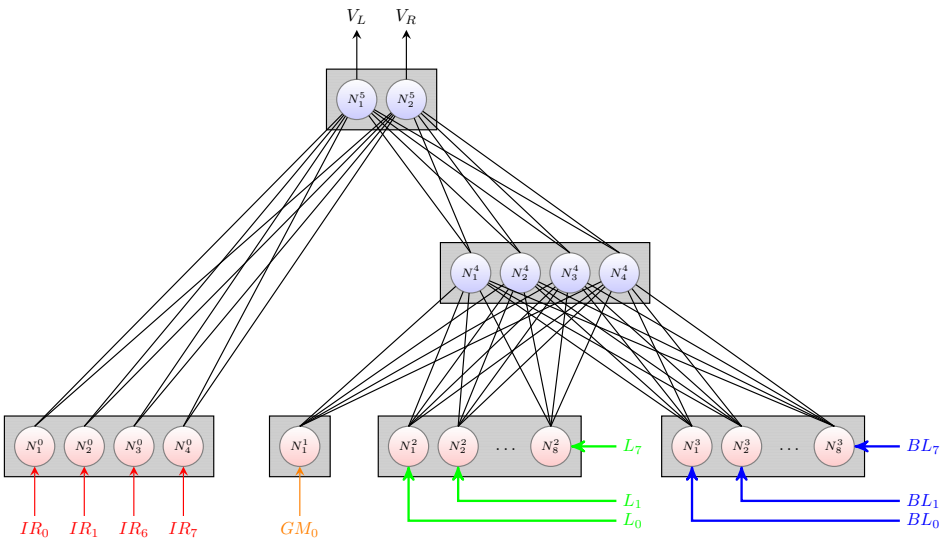
ANN: Exp 4



- Cromosoma:

Recolección

ANN: Exp 4

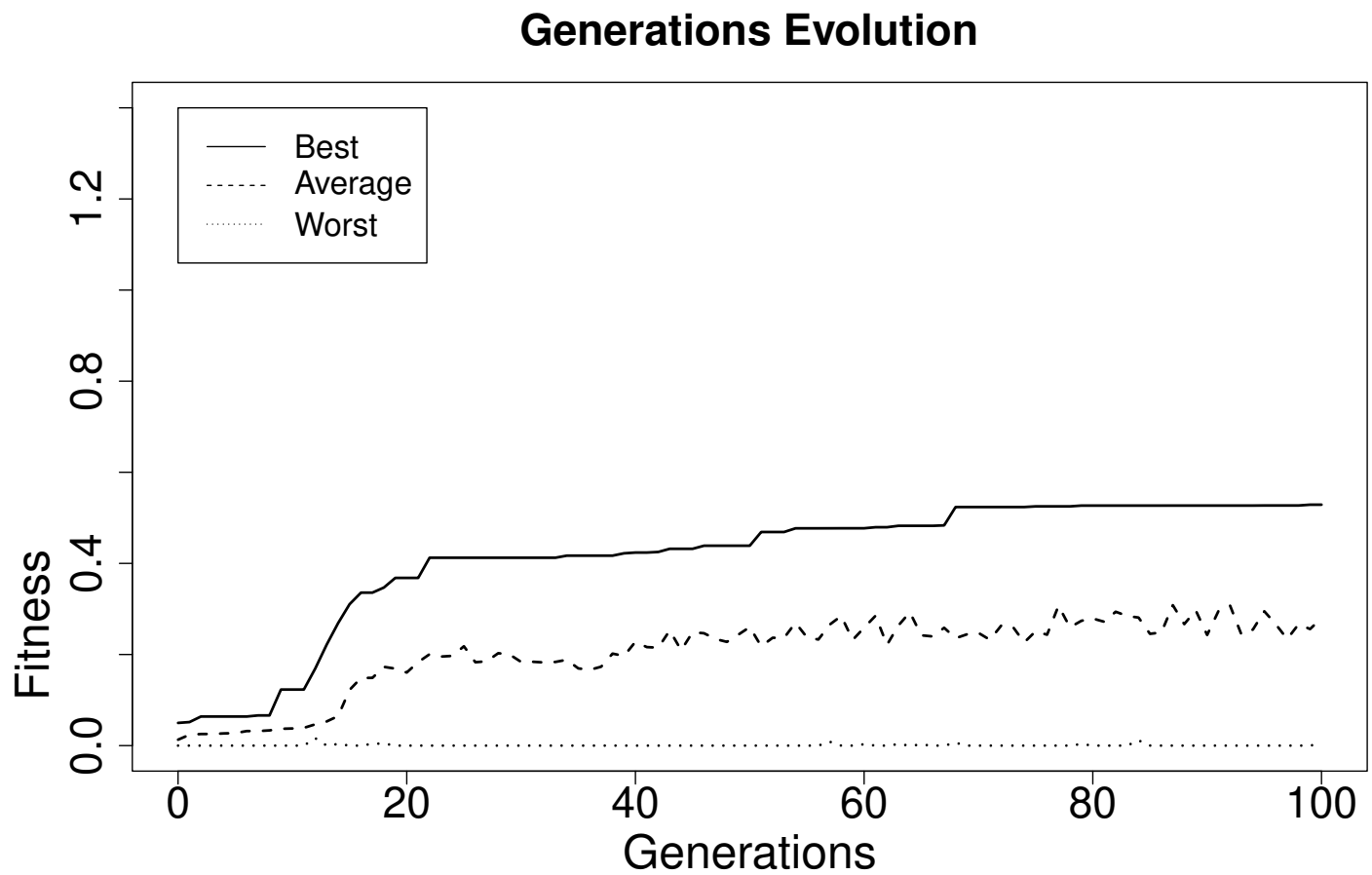


- Cromosoma: 90
- Población: 50
- Mutación: 2 %
- Tiempo eval: 300 s.
- Elites: 4

$$F = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7) \right]}{N_{steps}} \left(1 - min \left\{ \frac{N_{coll}, 10}{10} \right\} \right) \left(\frac{F_{obj}}{20} \right)$$

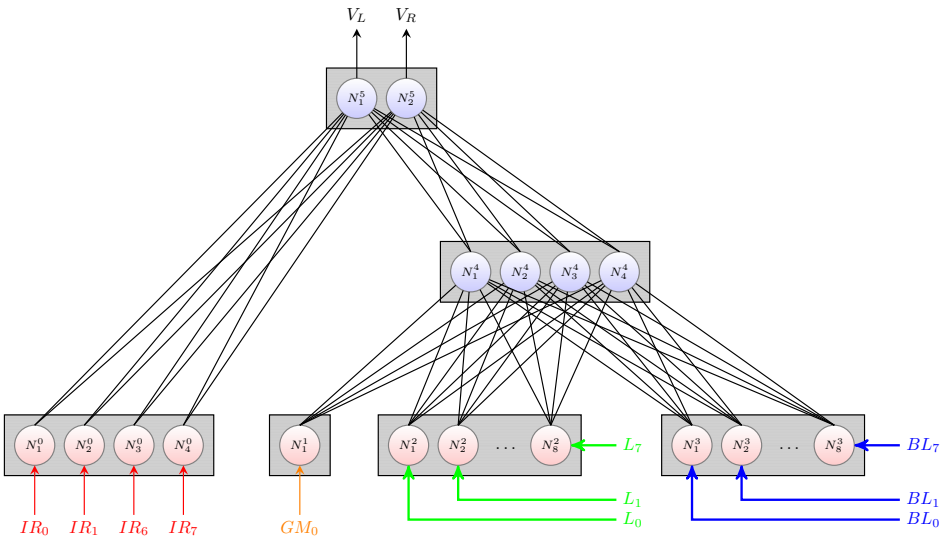
Recolección

ANN: Exp 4



Recolección

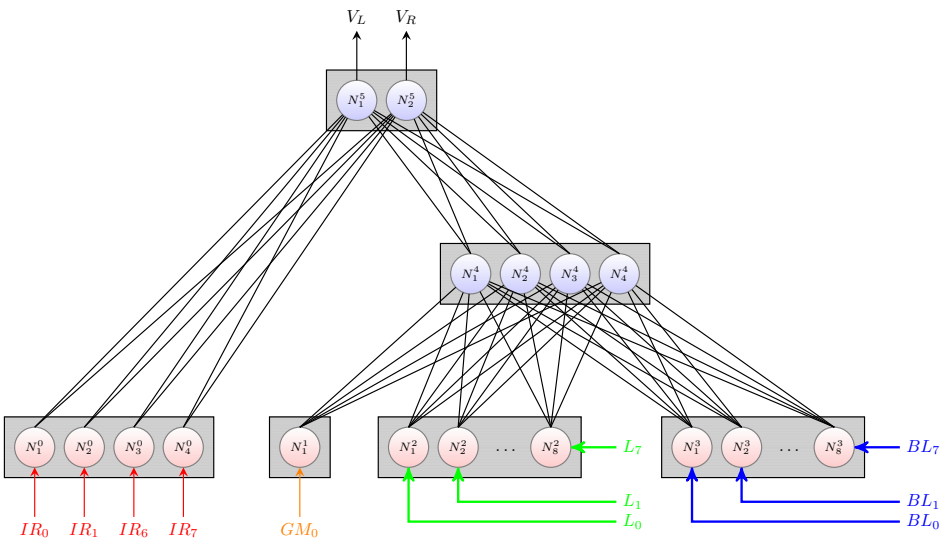
ANN: Exp 5



- Cromosoma:

Recolección

ANN: Exp 5



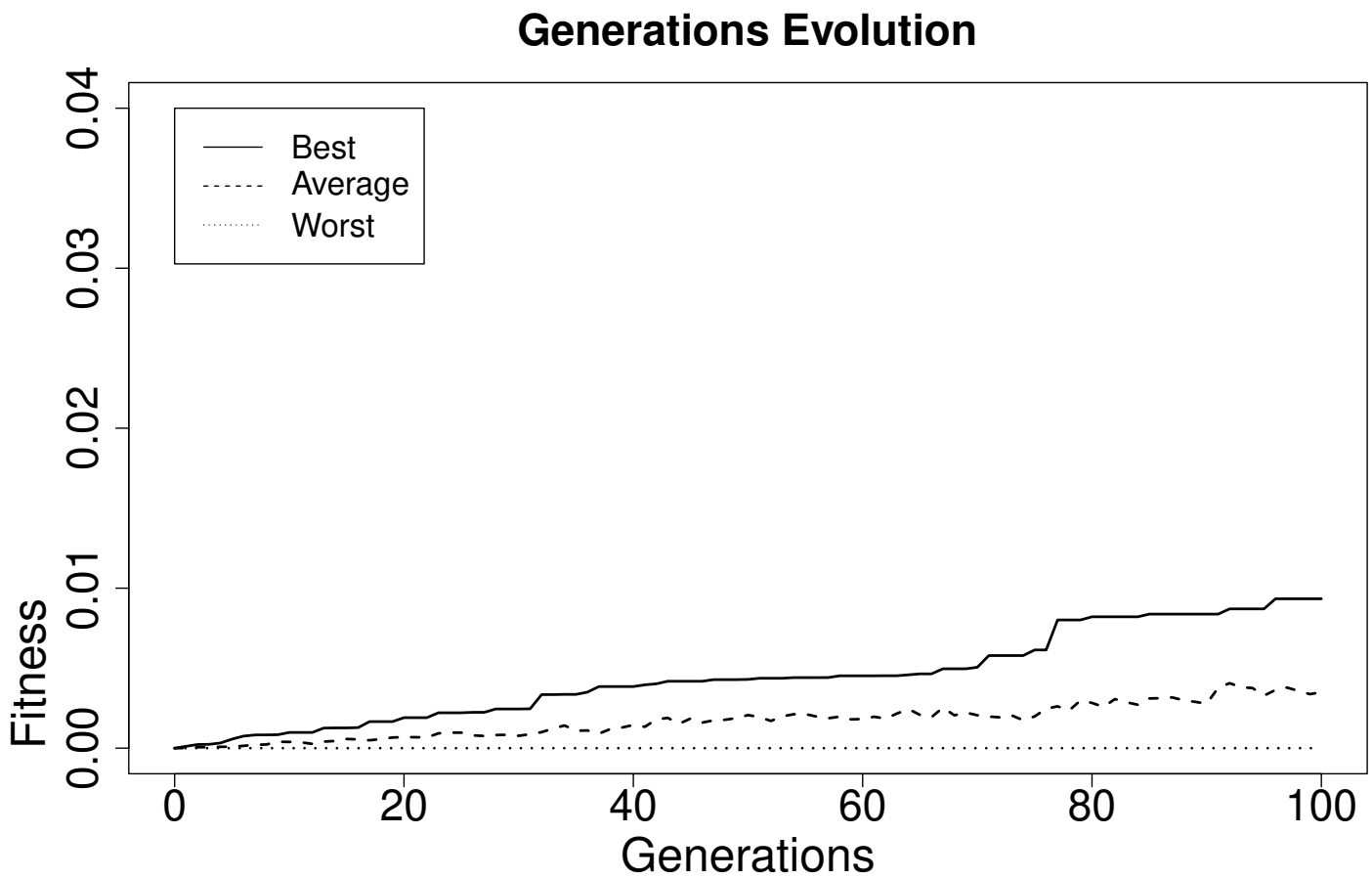
- Cromosoma: 90
- Población: 50
- Mutación: 2 %
- Tiempo eval: 300 s.
- Elites: 4

Inicialización Aleatoria (5)

$$F = \frac{\sum_{i=0}^{N_{steps}} (1 - max\{IR_i\}) \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7) \right]}{N_{steps}} \left(\frac{F_{obj}}{20} \right)$$

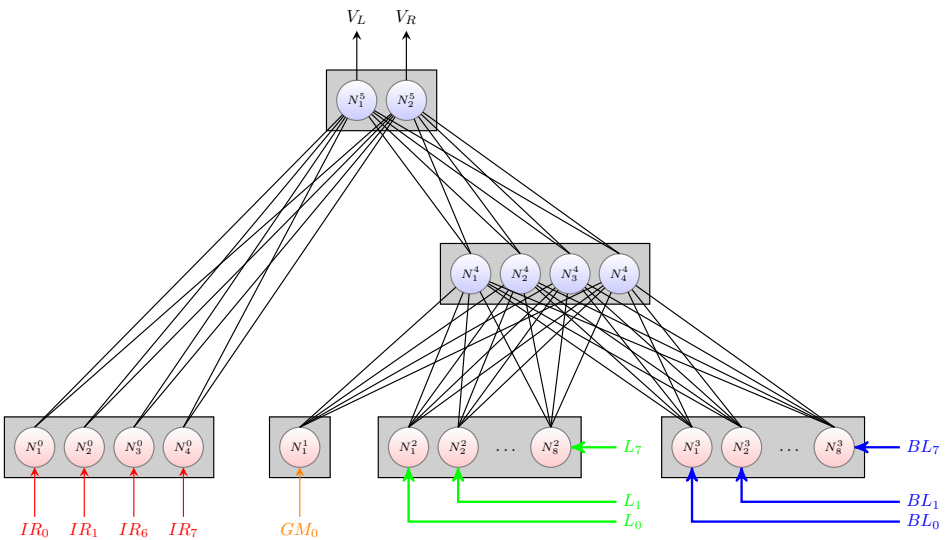
Recolección

ANN: Exp 5



Recolección

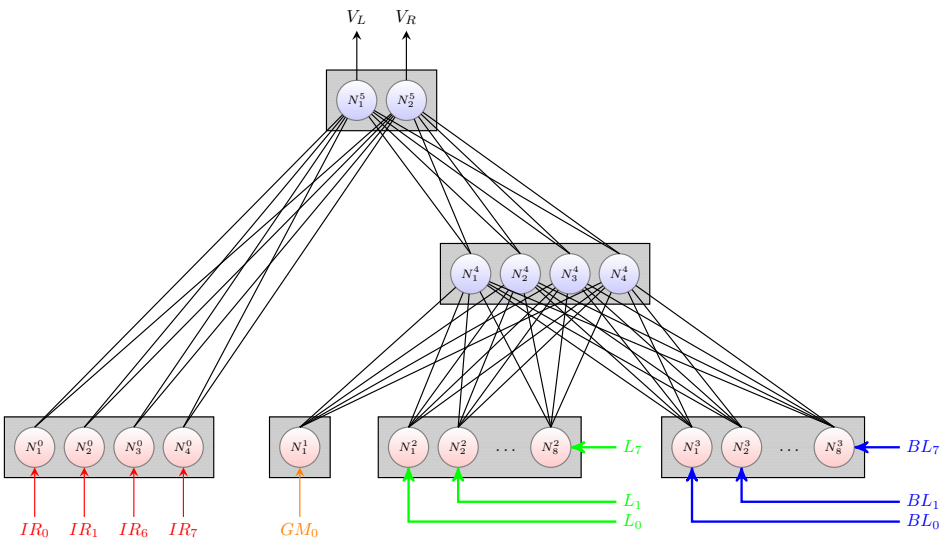
ANN: Exp 6



- Cromosoma:

Recolección

ANN: Exp 6



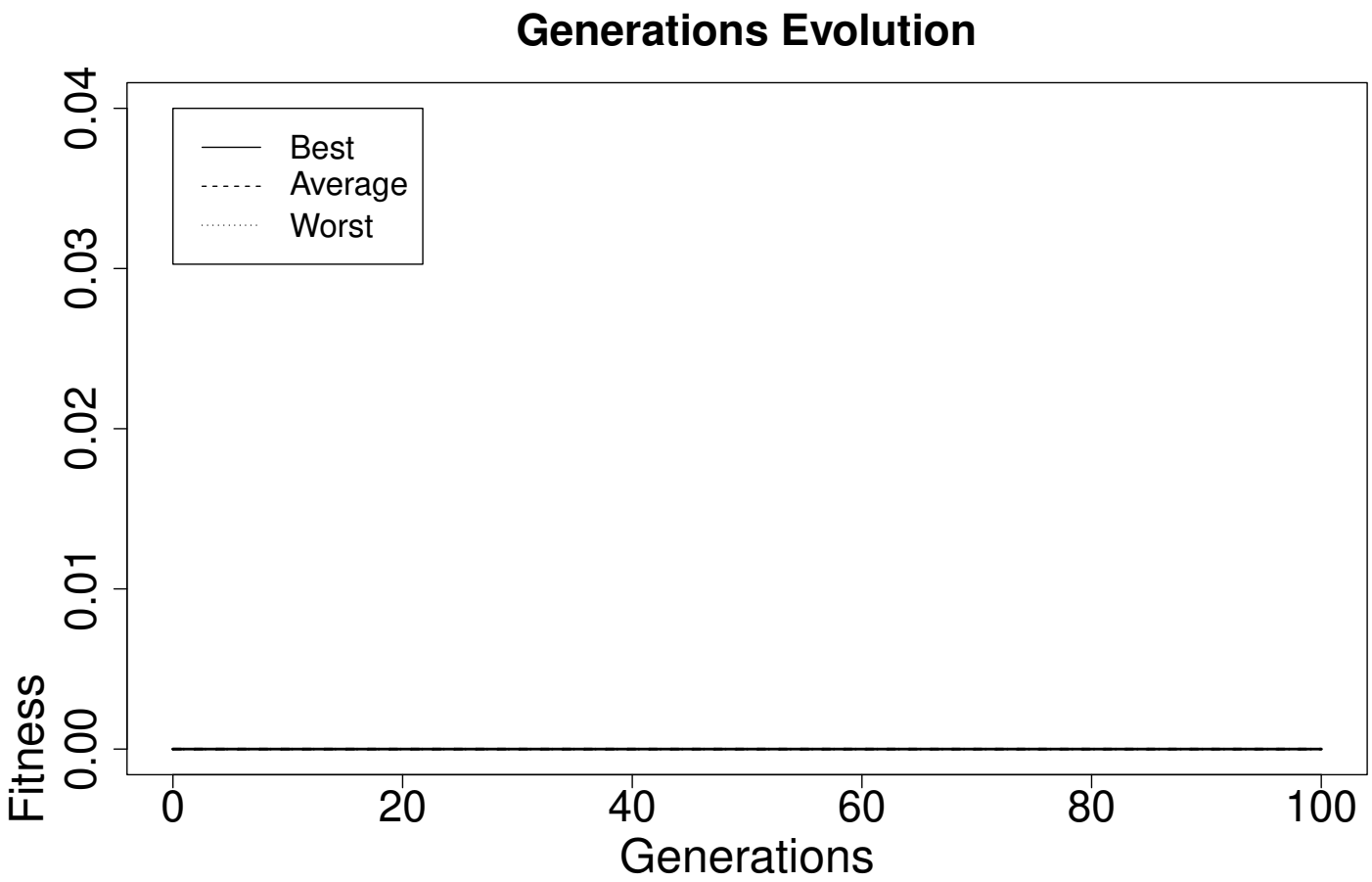
- Cromosoma: 90
- Población: 50
- Mutación: 2 %
- Tiempo eval: 300 s.
- Elites: 4

Inicialización de Objectos Aleatoria (20)

$$F = \frac{\sum_{i=0}^{N_{steps}} (1 - max\{IR_i\}) \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7)\right]}{N_{steps}} \left(\frac{F_{obj}}{20}\right)$$

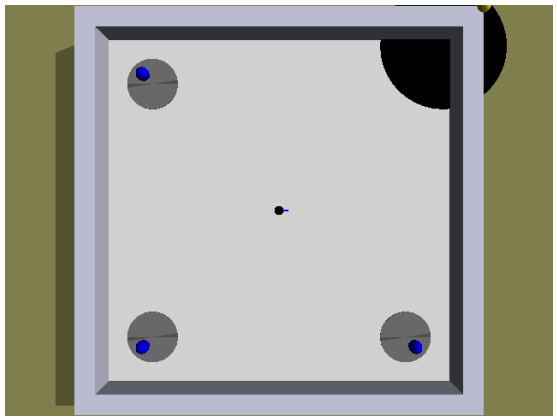
Recolección

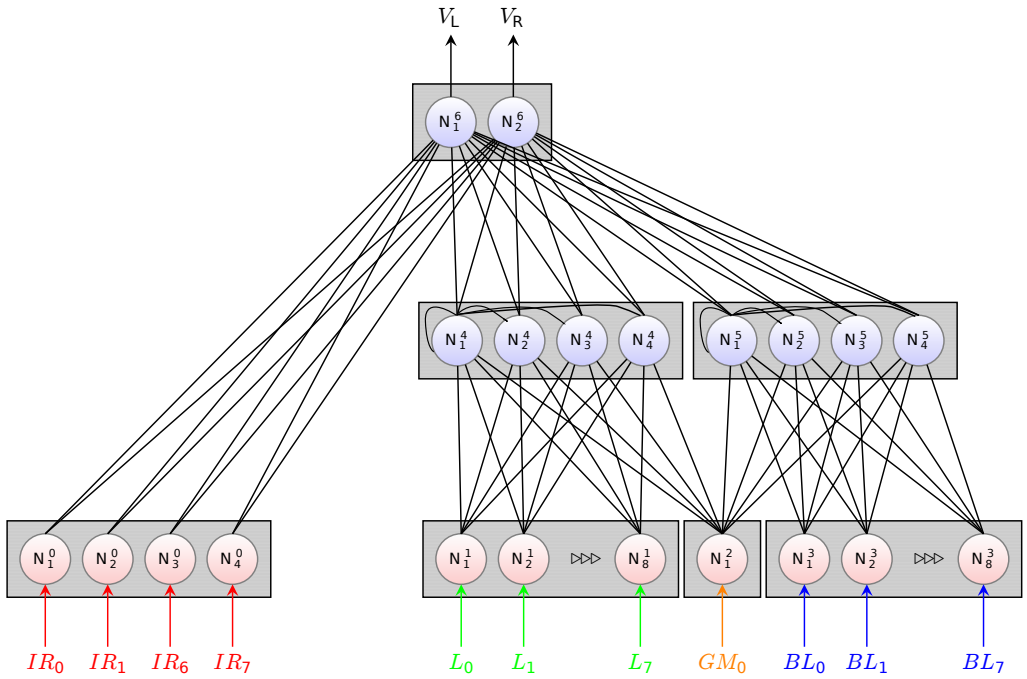
ANN: Exp 6



Recolección

CTRNN: Exp 6

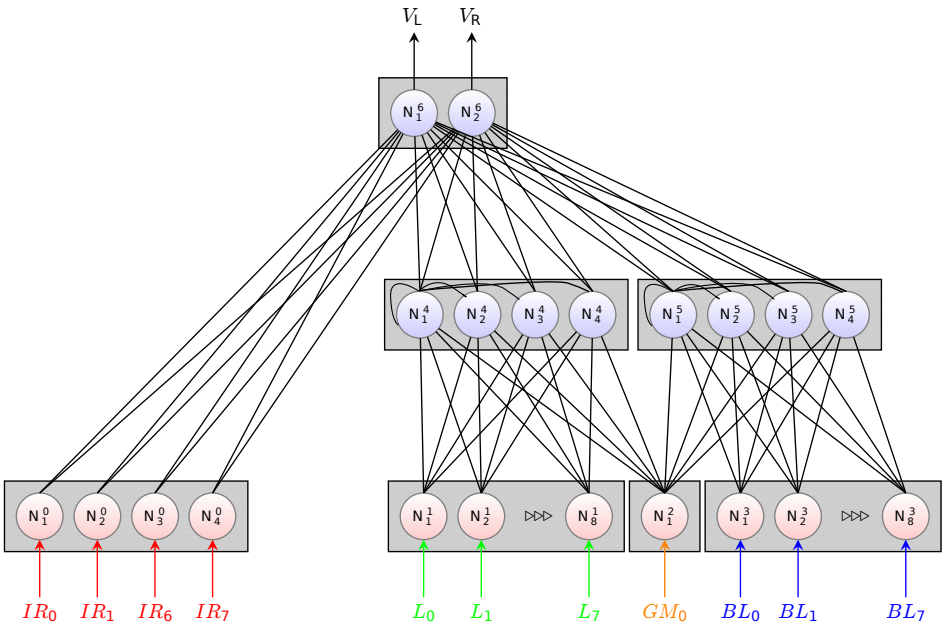




$$F = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7) \right]}{N_{steps}} \left(1 - min\left\{\frac{N_{coll}, 30}{30}\right\}\right)\left(\frac{F_{obj}}{5}\right)$$

Recolección

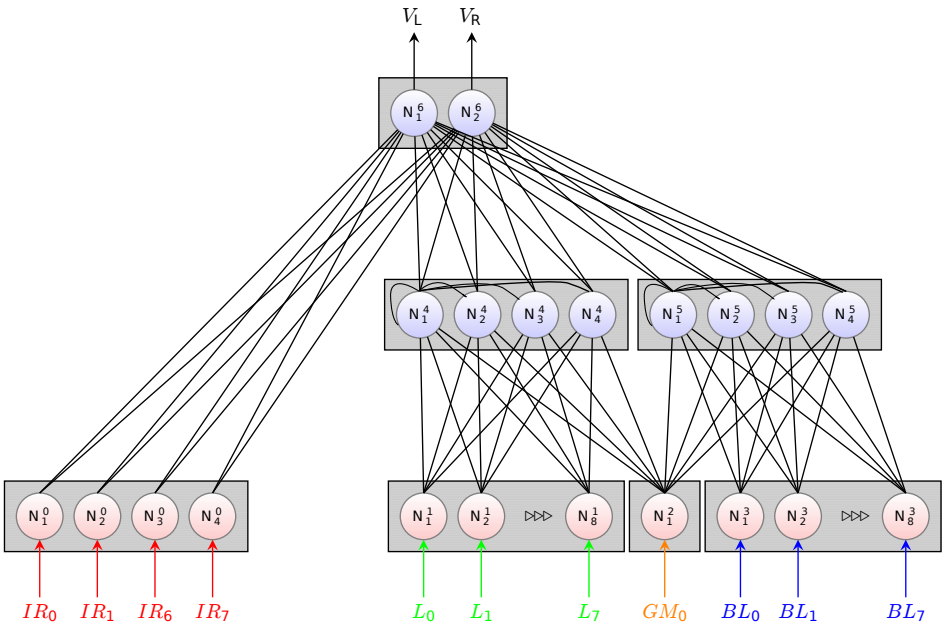
CTRNN: Exp 6



- Cromosoma:

Recolección

CTRNN: Exp 6



- Cromosoma: 158
- Población: 50
- Mutación: 10 %
- Tiempo eval: 500 s.
- Elites: 6
- **Generaciones: 2000**

$$F = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}\left(BL_0 + BL_7\right) + GM_{on}\left(L_0 + L_7\right) \right]}{N_{steps}} \left(1 - min\left\{\frac{N_{coll}, 30}{30}\right\}\right)\left(\frac{F_{obj}}{5}\right)$$

Recolección

CTRNN: Exp 6
Evolución por partes

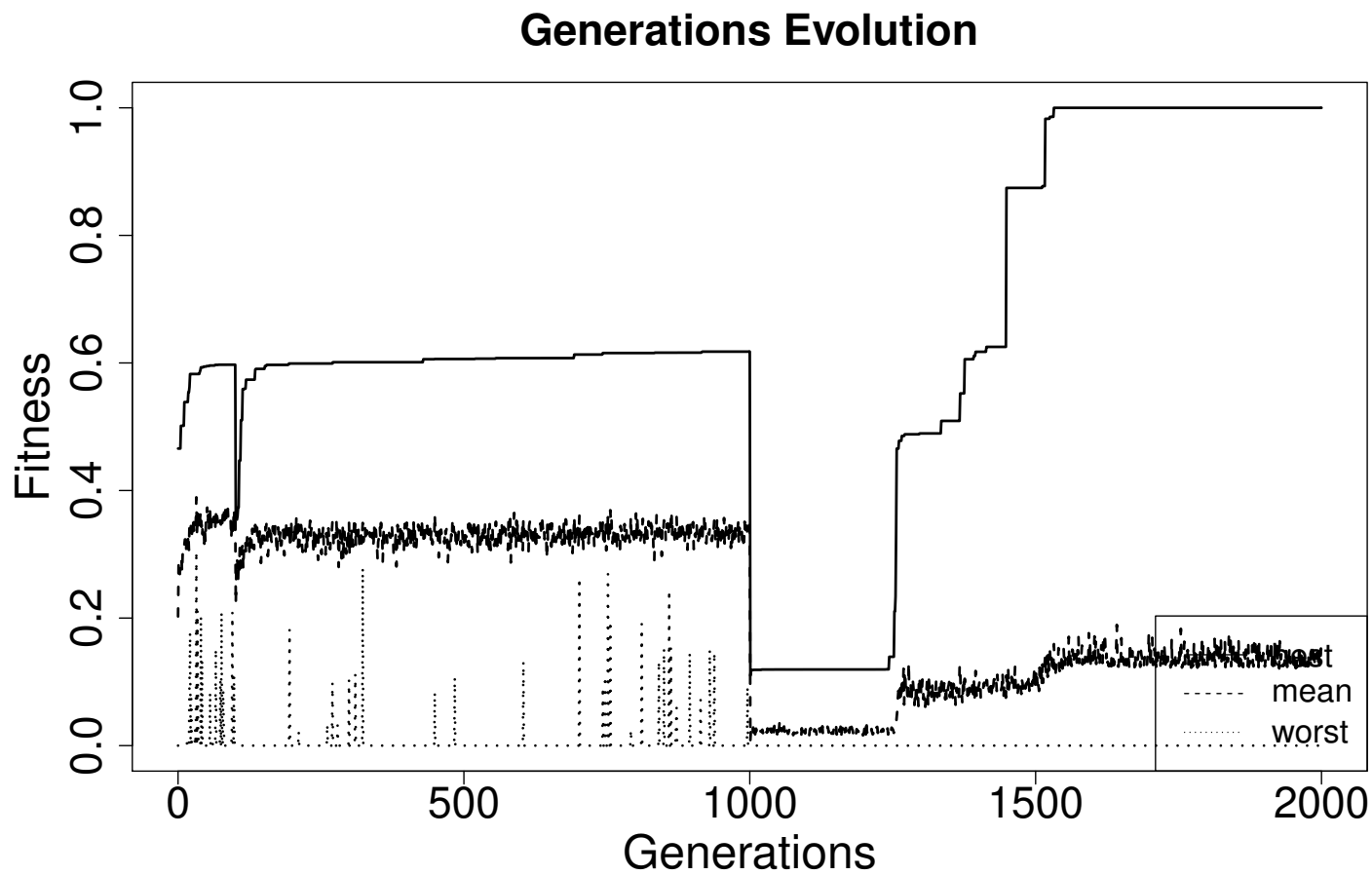
$$F_{0:100} = \frac{\sum_{i=0}^{N_{steps}} \frac{BL_0 + BL_7}{2}}{N_{steps}} \cdot \left(1 - min\left\{\frac{N_{coll}, 10}{10}\right\}\right)$$

$$F_{101:1000} = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7)\right]}{N_{steps}} \left(1 - min\left\{\frac{N_{coll}, 10}{10}\right\}\right)$$

$$F_{1001:2000} = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7)\right]}{N_{steps}} \left(1 - min\left\{\frac{N_{coll}, 30}{30}\right\}\right) \left(\frac{F_{obj}}{5}\right)$$

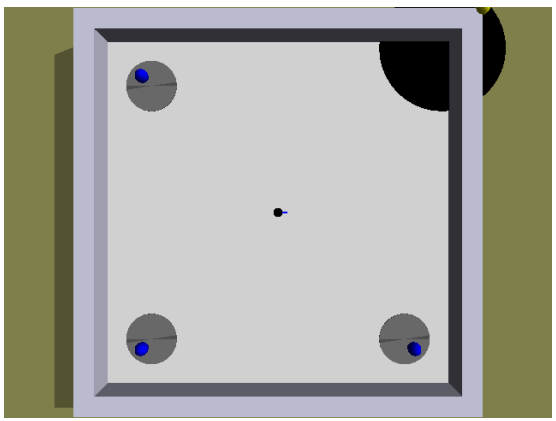
Recolección

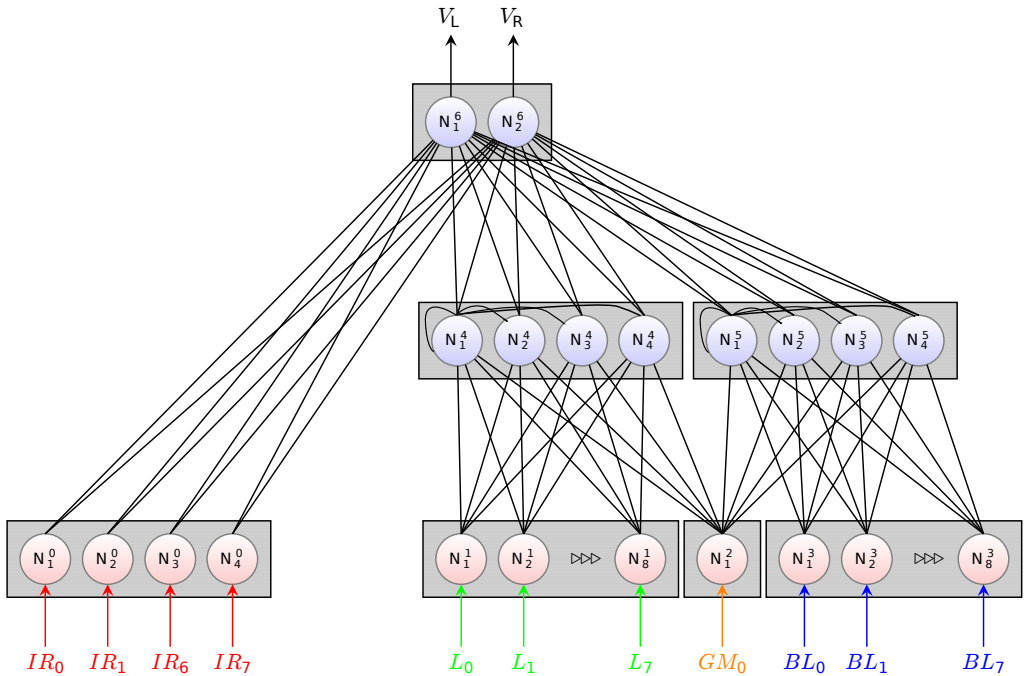
CTRNN: Exp 6



Recolección

CTRNN: Exp 8

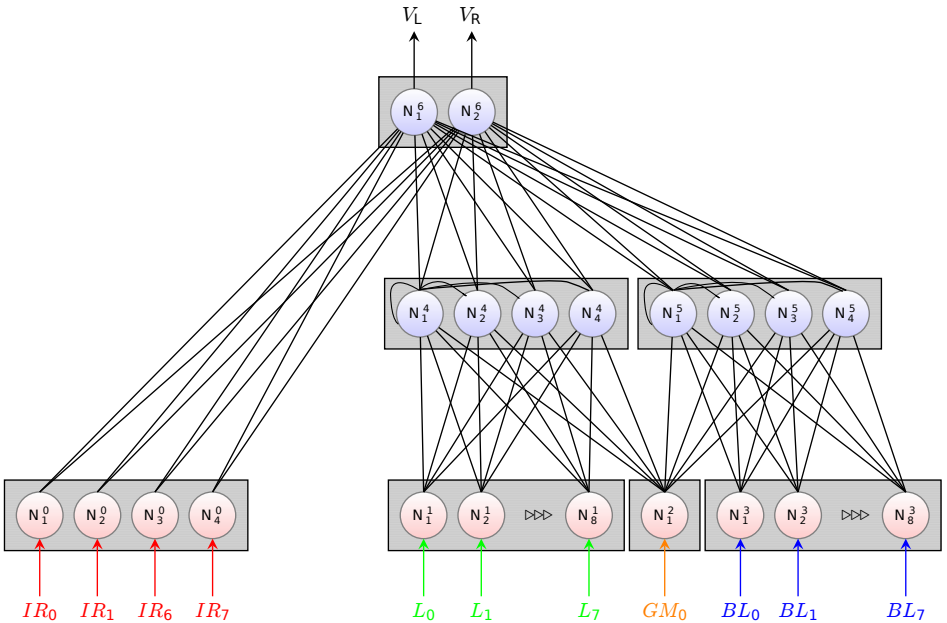




$$F = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}(BL_0 + BL_7) + GM_{on}(L_0 + L_7) \right]}{N_{steps}} \left(1 - min \left\{ \frac{N_{coll}, 30}{30} \right\} \right) \left(\frac{F_{obj}}{5} \right)$$

Recolección

CTRNN: Exp 8

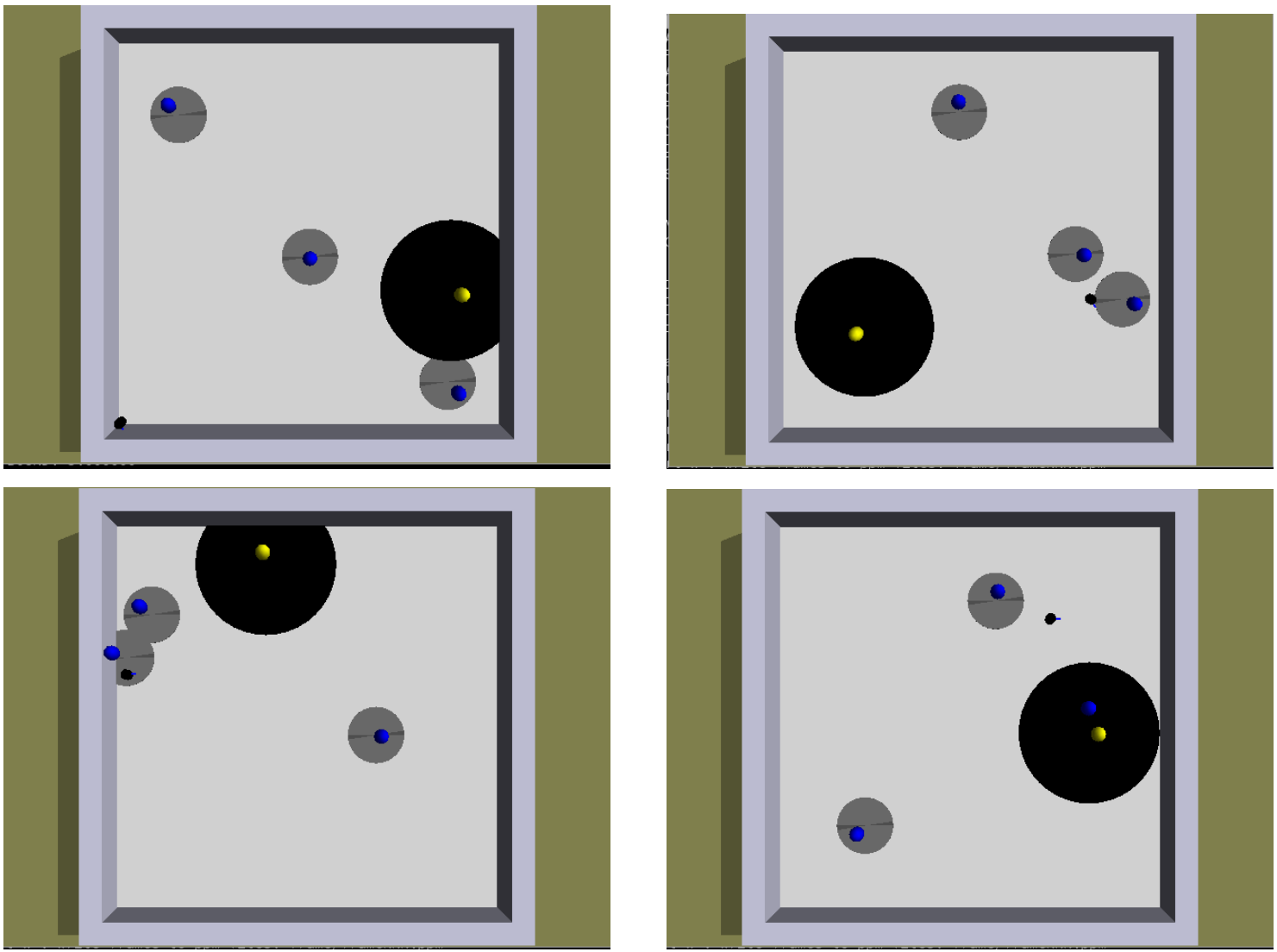


- **Muestras por cromosoma: 4**
- **Entorno Aleatorio**
- **Generaciones: 3000**

$$F = \frac{\sum_{i=0}^{N_{steps}} \left[GM_{off}\left(BL_0 + BL_7\right) + GM_{on}\left(L_0 + L_7\right) \right]}{N_{steps}} \left(1 - min\left\{\frac{N_{coll}, 30}{30}\right\}\right)\left(\frac{F_{obj}}{5}\right)$$

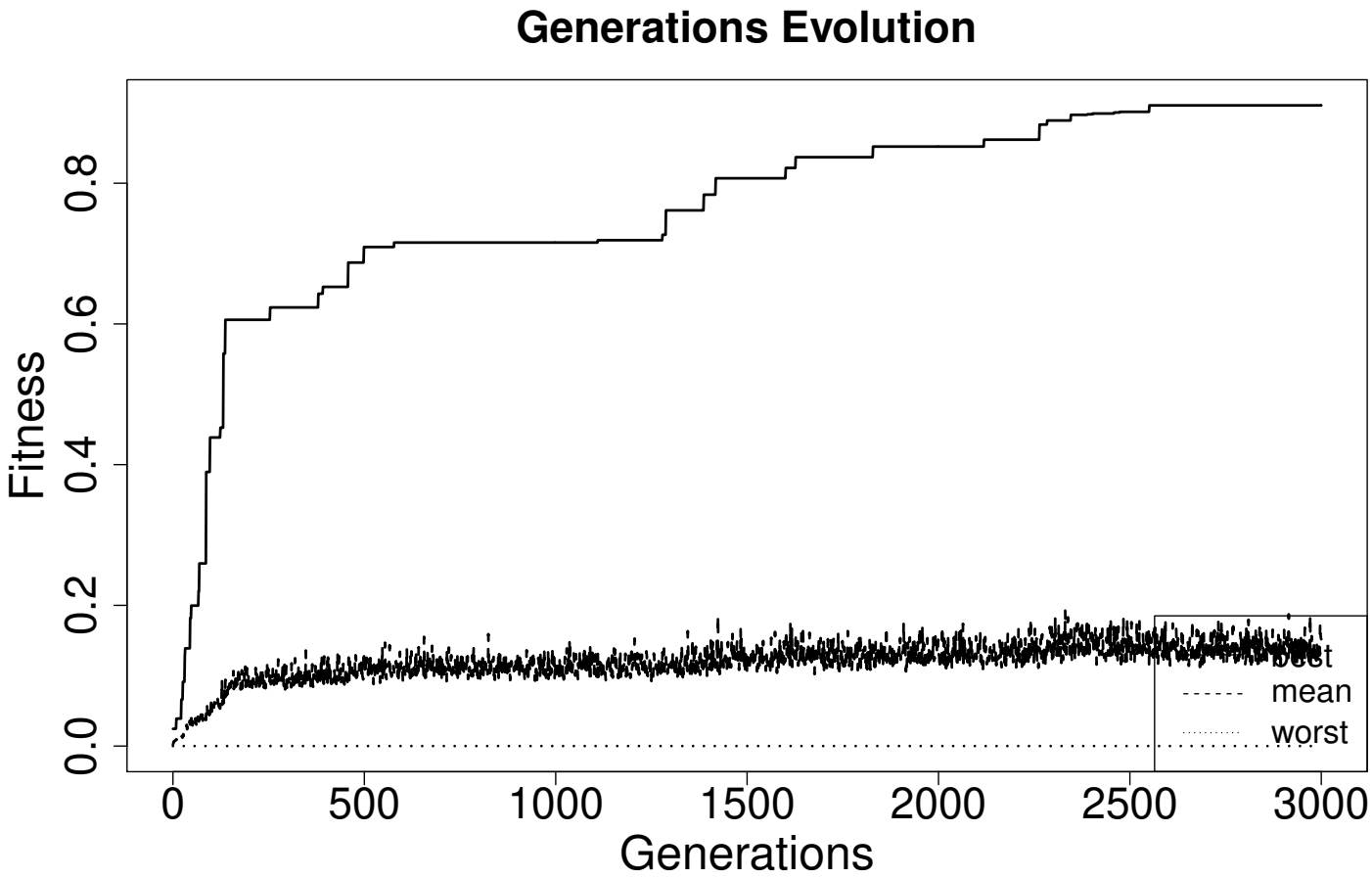
Recolección

CTRNN: Exp 8

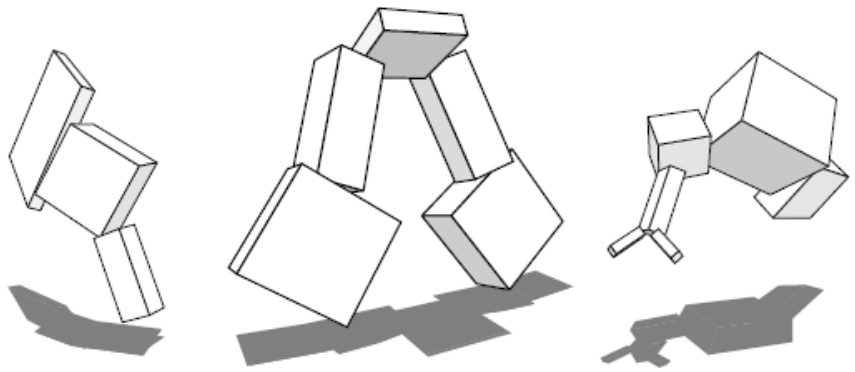


Recolección

CTRNN: Exp 8



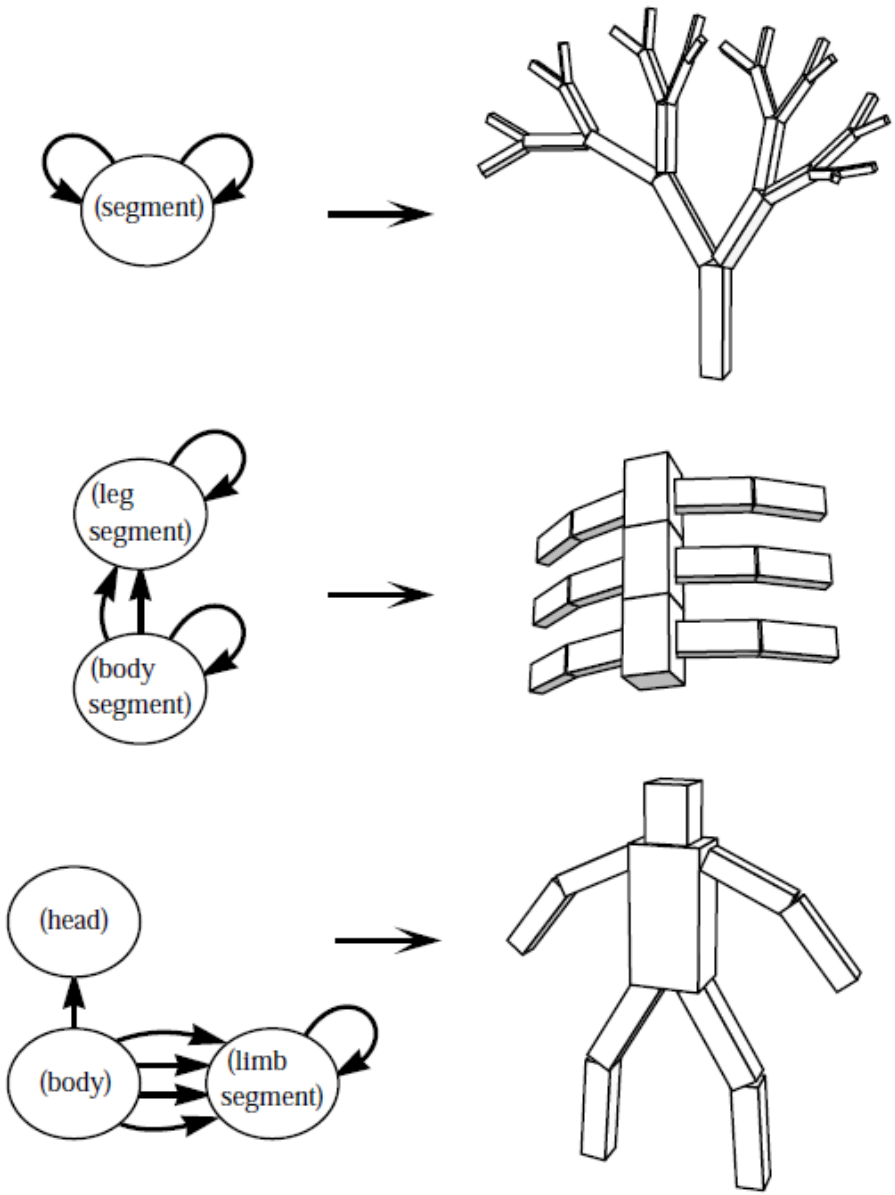
Evolución de Morfología



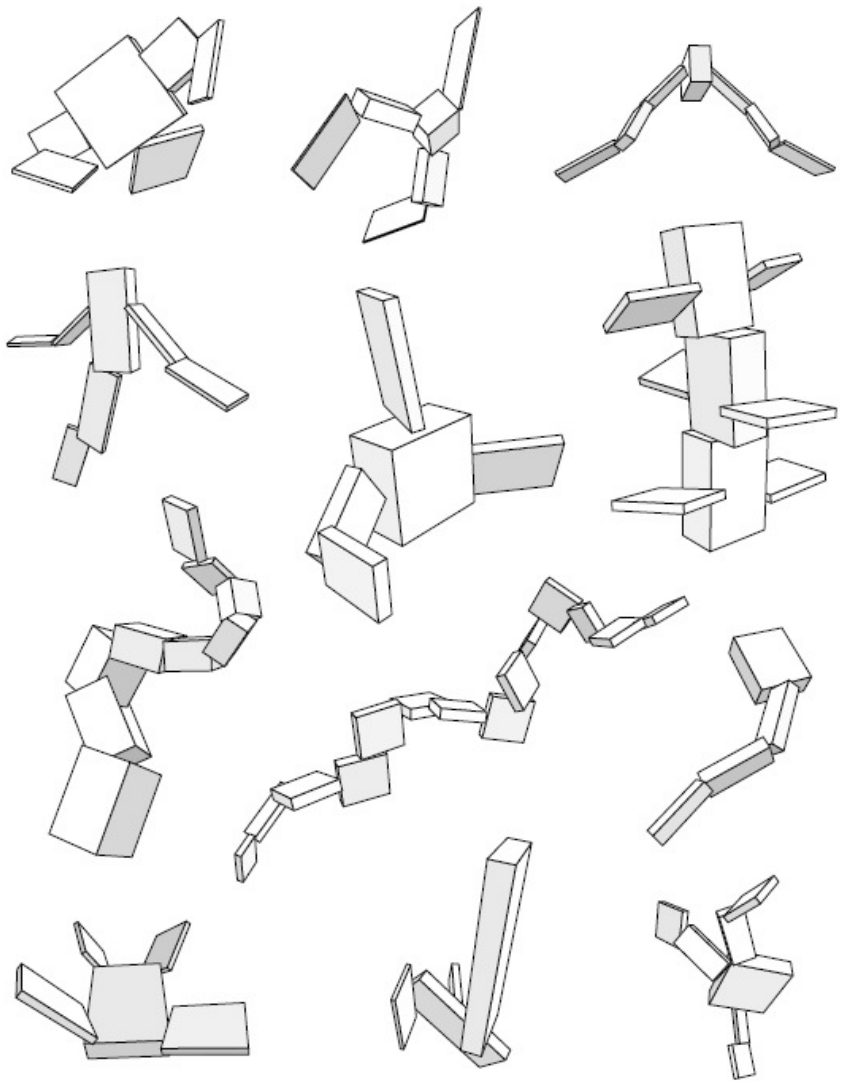
Evolving Virtual Creatures (Sims, 1994)

Evolución de Morfología

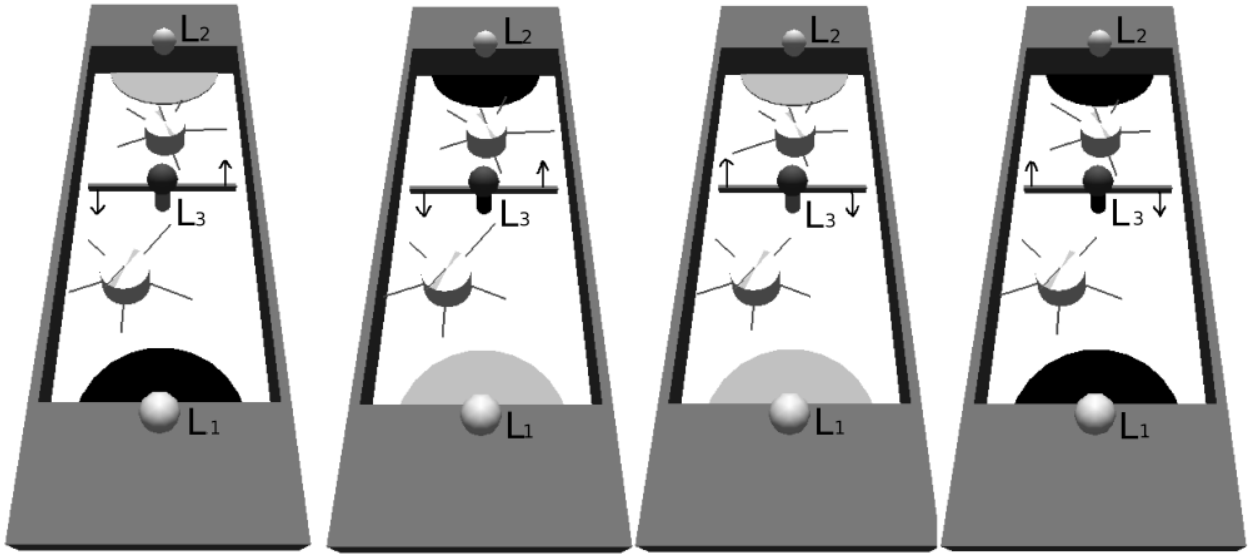
- El genotipo especifica como se genera el fenotipo
- Forma, longitud, tipo de uniones, ángulos, etc, etc, etc, sujetos a variación genética
- Fitness: Nadar, caminar, saltar, seguir objetos, coger el control de un cubo, ...



Evolución de Morfología

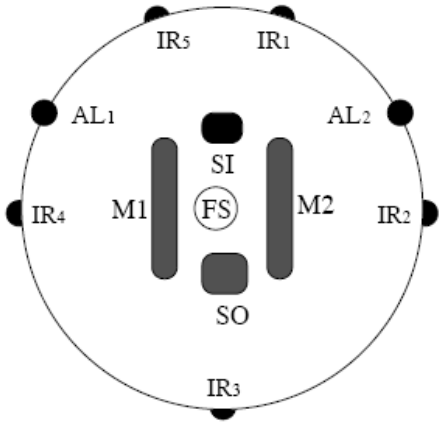


Cooperación

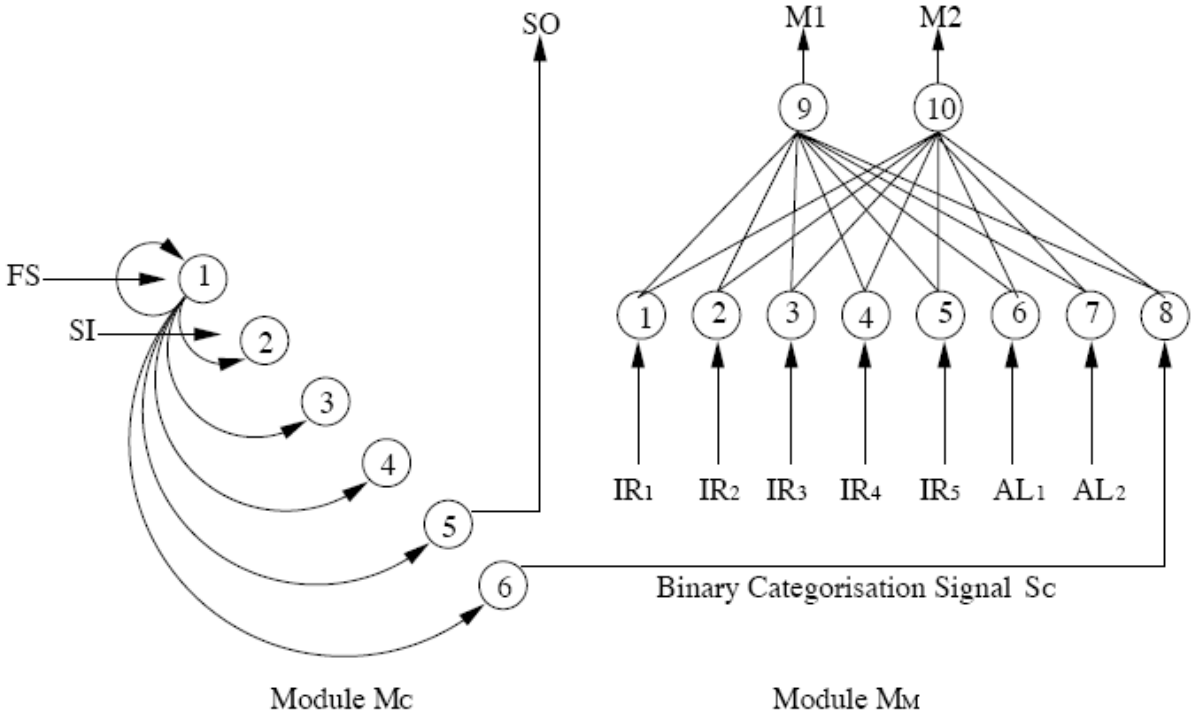


Evolution of Acustic Communication Between Two Cooperating Robots (Tuci y Ampatzis, 2007)

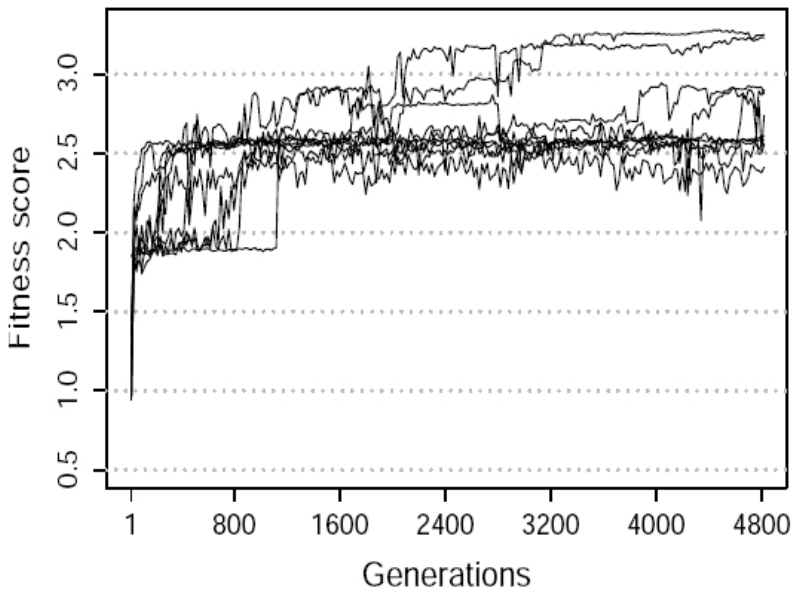
Cooperación

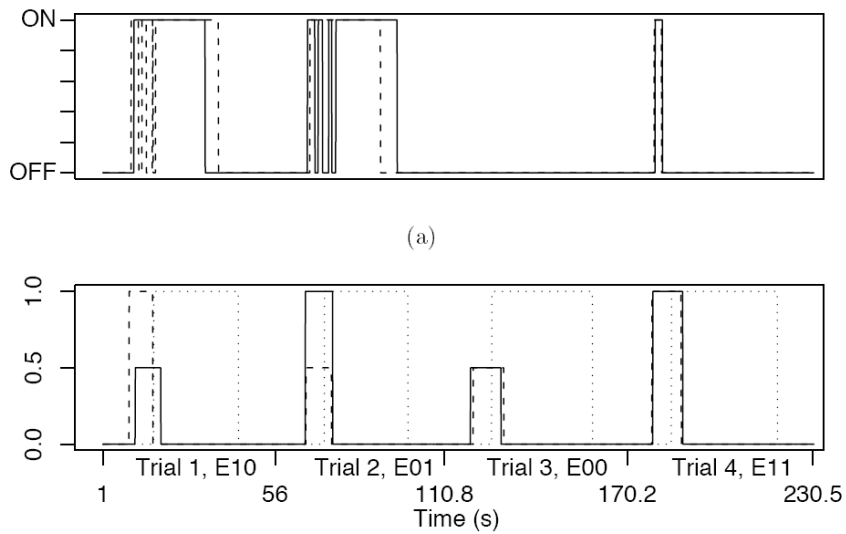


- 2 Motores
- 5 Sensores de Infrarrojo
- 2 Sensores de Luz
- 1 Sensor de Suelo
- 1 Micrófono
- 1 Altavoz



Cooperación

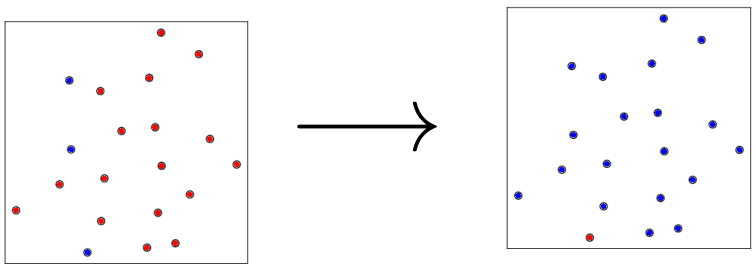




Comunicación

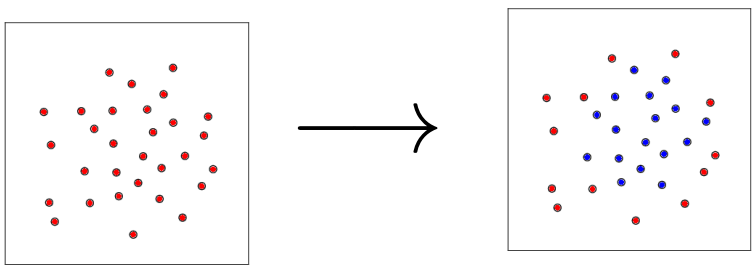
Exp. A: Leader Selection

- Only a single agent claims the leadership of the swarm.



Exp.B: Borderline Identification

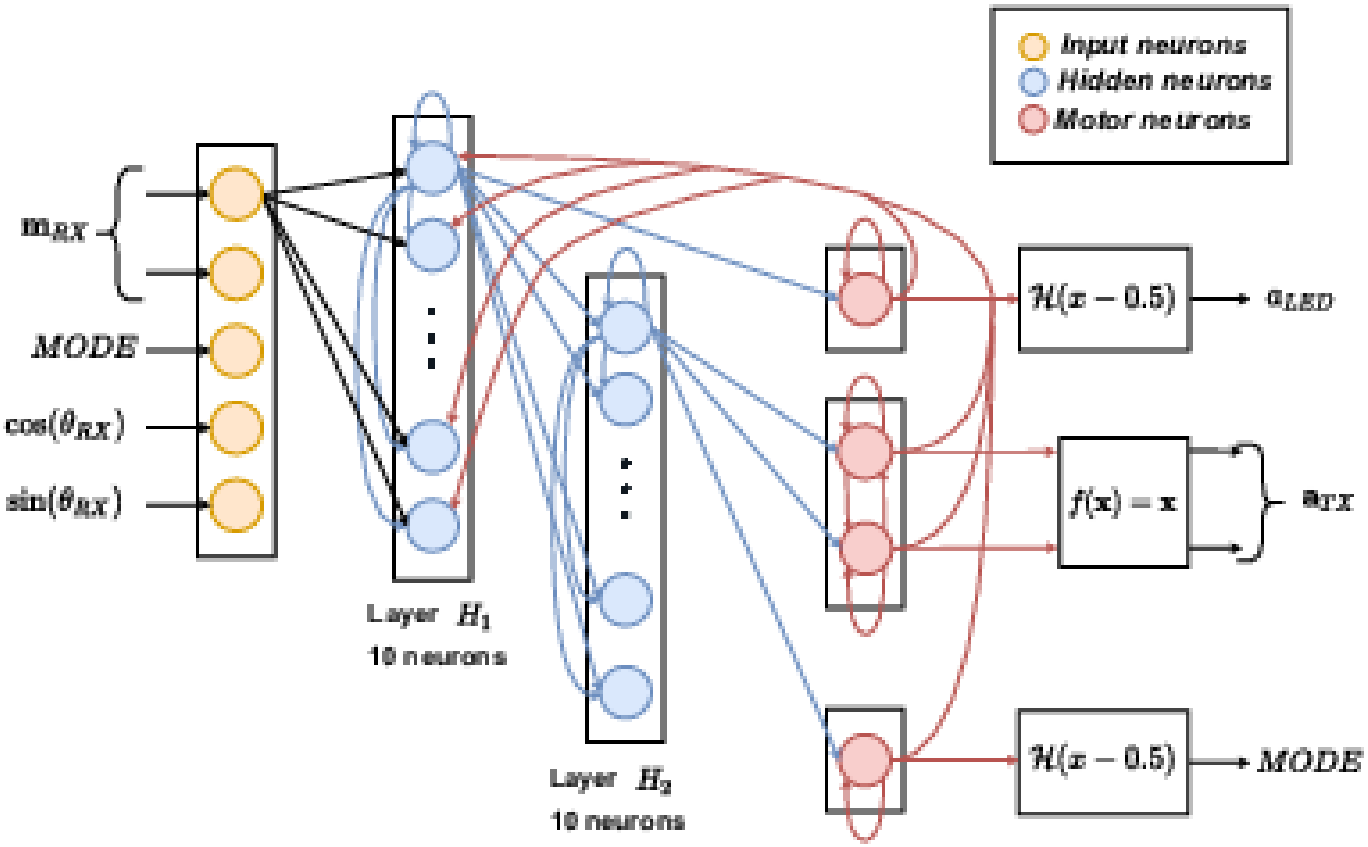
- Identify the robots within the swarm frontier or borderline.



Evolution of Situated and Abstract Communication in Leader Selection and Borderline Identification Swarm Robotics Problems (Sendra y Gutiérrez, 2021)

Comunicación

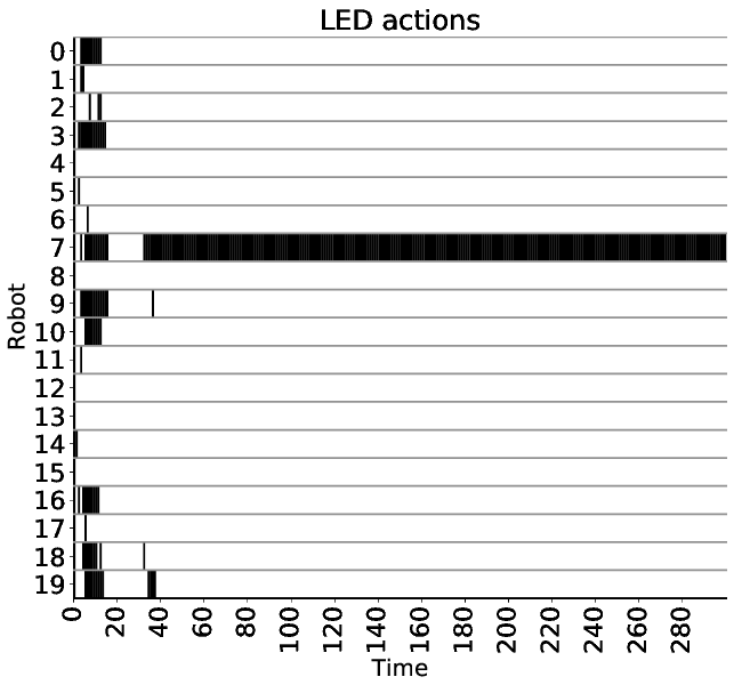
- Experiments A and B:

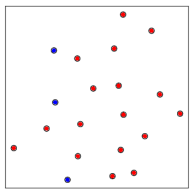


Comunicación

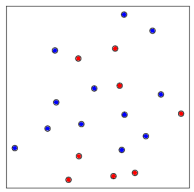
2 fases

1. Negociación
2. Elección

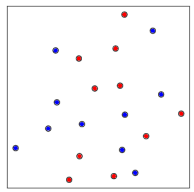




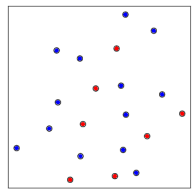
(a) Time step 1



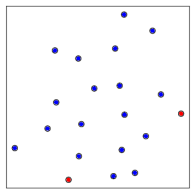
(b) Time step 3



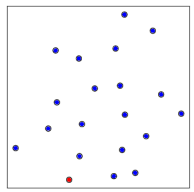
(c) Time step 5



(d) Time step 10



(e) Time step 15



(f) Time step 40

Conclusiones

- Por qué
  - No somos buenos diseñando sistemas emergentes
  - La robótica evolutiva puede ser la solución
- Sin embargo:
  - Los comportamientos evolucionados son normalmente difíciles de analizar
  - Aún no se ha demostrado una diferencia con respecto a los diseños manuales
  - Aún no sabemos si se pueden evolucionar comportamientos complejos
  - Es posible que solo sea una herramienta más

Gracias

GRACIAS!!

Gracias

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