Towards an Adaptive Lévy Walk Using Artificial Endocrine Systems

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Hugo Sardinha received his MSc in Mechanical Engineering with a specialism in Control Systems, from Instituto Superior Técnico (IST), Lisbon University in 2012. After working for 3 years industry he rejoined academia and received a MSc in Robotics, Autonomous and Interactive Systems from Heriot-Watt University, in 2016. Currently he is a PhD candidate at the Edinburgh Centre for Robotics working on adaptive behaviours for aerial swarm robotics.

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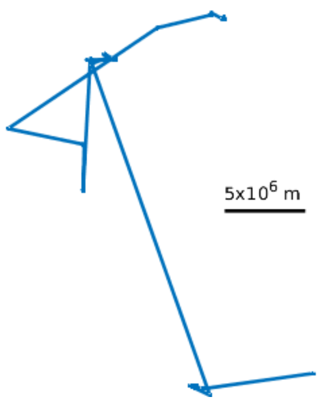
Motivation

- Foraging animals exhibit a behaviour that couples periods of localized search with ballistic relocation, i.e., Lévy Walk.
- Switching between these behaviours occurs due to changes in the environment.
- Can artificial endocrine systems be used as an adaptation mechanism to manage exploitation and exploration?

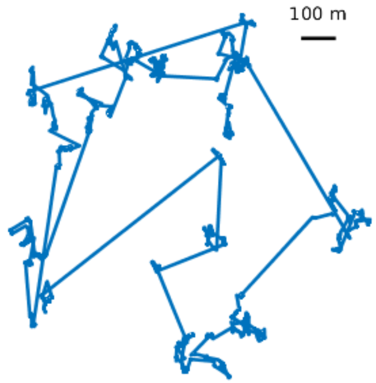
Lévy Walks

Random walks where step lengths are drawn from a power law

$$P(l_s) \sim l_s^{-\mu}, \quad 1 < \mu \leq 3$$



$\mu = 1.5$



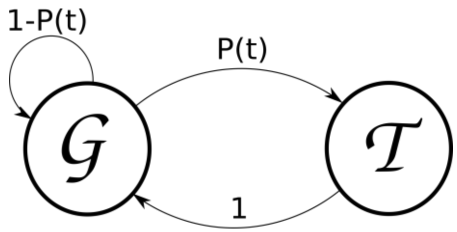
$\mu = 2$

$\mu = 2.5$

Biological Fluctuation (Yuragi)

Yuragi

Finite State Machine Model



$$\dot{\mathbf{x}}(t) = -\nabla U(\mathbf{x}(t))A(t) + \epsilon(t) \tag{1}$$

$$A(t) = R \cdot A(t-1) + f(t) \tag{2}$$

$$U(\mathbf{x}(t)) = (\mathbf{x}(t) - h)^2 \tag{3}$$

$$P(t) = e^{-\mathbf{x}(t)} \tag{4}$$

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Endocrine Lévy Walk (ELW)

Endocrine Lévy Walk

Hormone Variation Model

$$H(t) = c_0 + c_1 H(t-1) + c_2 S(t)$$

Hormone level at time *t*

Hormone level at time *t-1*

Outside stimulus at time *t*

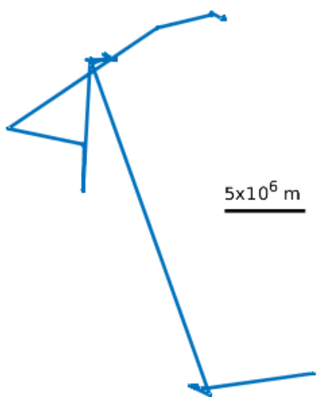
Settling point of *H(t)*

$$H_s = c_0/(1 - c_1)$$

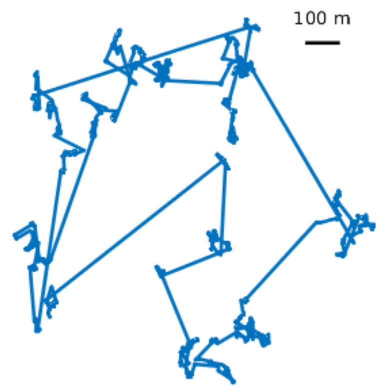
Endocrine Lévy Walk

Recall that Lévy walks are random walks where step lengths are drawn from a power law

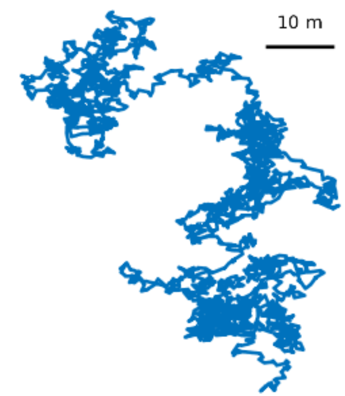
$$P(l_s) \sim l_s^{-\mu}, \quad 1 < \mu \leq 3$$



$\mu = 1.5$



$\mu = 2$



$\mu = 2.5$

Endocrine Lévy Walk

Adaptation of the μ parameter

$$\mu(t) = a_0 + a_1\mu(t-1) + a_2 S_\mu(t)$$

$$\mu(t) \rightarrow \mu_s = a_0/(1-a_1)$$

$$S_\mu(t) = \begin{cases} 1, & \Delta f(t) > 0 \\ 0, & \Delta f(t) \leq 0 \end{cases}$$

Endocrine Lévy Walk

Adaptation of the μ parameter

$$\mu(t) = a_0 + a_1\mu(t-1) + a_2 S_\mu(t)$$

$$\mu(t) \rightarrow \mu_s = a_0/(1-a_1)$$

$$S_\mu(t) = \begin{cases} 1, & \Delta f(t) > 0 \\ 0, & \Delta f(t) \leq 0 \end{cases}$$

Include a *desire (β)* to interreput the current walk l_s

$$\beta(t) = b_1\beta(t-1) + b_2 S_\beta(t)$$

$$S_\beta(t) = \begin{cases} 0, & \Delta f(t) \geq 0 \\ \dfrac{\bar{\mu} - \mu(t)}{\bar{\mu} - \mu_s}, & \Delta f(t) < 0 \end{cases}$$

$$l_s = l_s\Big(1 - \beta(t)\Big)$$

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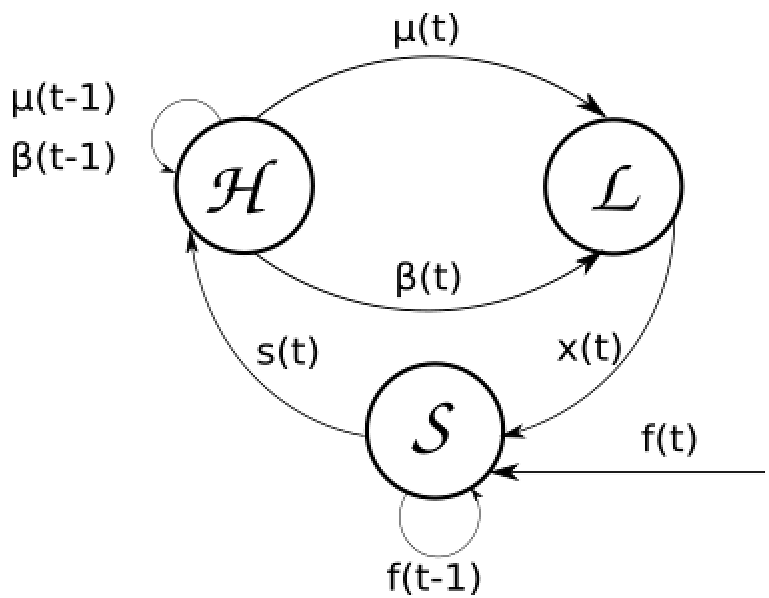
Endocrine Lévy Walk



Endocrine Lévy Walk

Optimising the ELW parameters via Genetic Algorithms

Settling point of μ

$$\mu_s \quad a_1 \quad a_2 \quad b_1 \quad b_2$$

Weight of the stimulus of β

Weight of the decay of μ

Weight of the decay of β

Weight of the stimulus of μ

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Endocrine Lévy Walk

Optimising the ELW parameters via Genetic Algorithms

Optimising function (Search Efficiency)

$$\underbrace{\eta = P}_{\text{Rewards Found}} / \underbrace{D}_{\text{Distance travelled}}$$

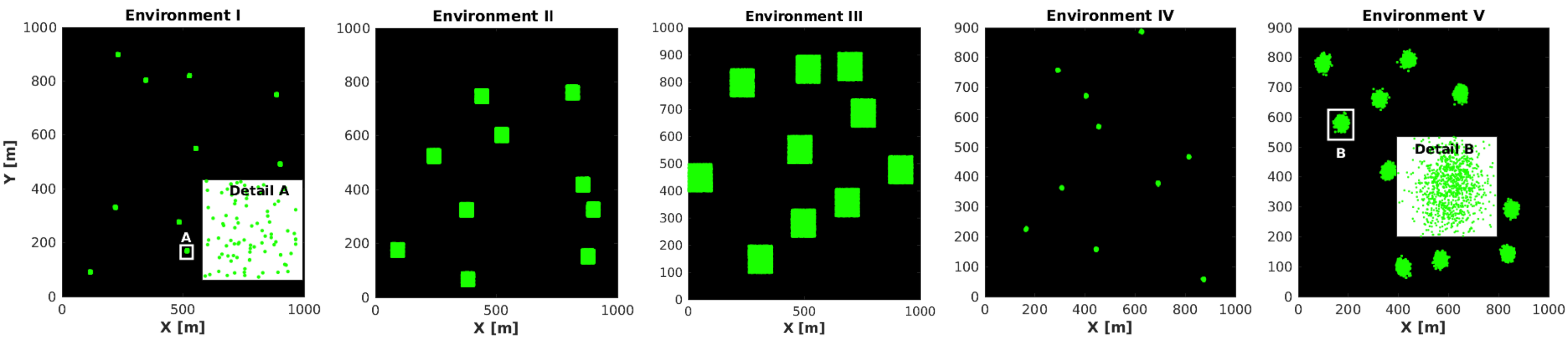
GA parameters

- Tournament selection size: 10
- Arithmetic Crossover
- Uniform Random Mutation
- Population Size: 250
- Elitism rate: 5%
- Generations: 250

RESULTS

RESULTS

Test Environments



RESULTS

Yuragi

$$\dot{\mathbf{x}}(t) = -\nabla U(\mathbf{x}(t))A(t) + \epsilon(t)$$

$$A(t) = R \cdot A(t-1) + f(t)$$

$$U(\mathbf{x}(t)) = (\mathbf{x}(t) - h)^2$$

$$P(t) = e^{-\mathbf{x}(t)}$$

SENSITIVITY ANALYSIS ON EFFICIENCY WITH VARYING R

Model	R	Env I	Env II	Env III	Env IV	Env V
A	0.99	0.26±0.11 (0.23±0.11)	8.98±2.38	19.74±3.51	0.35±0.13	3.93±0.99
B	0.90	0.29±0.10 (0.28±0.11)	7.41±1.98	24.07±4.48	0.29±0.11	3.19±0.89
C	0.50	0.21±0.09 (0.17±0.06)	6.72±1.61	20.70±4.69	0.24±0.10	2.49±0.79

RESULTS

METRIC COMPARISON BETWEEN YURAGI AND ELW

Search behaviour	Efficiency (10^{-2})	Rewards Found (10^{2})	Patches Found
ELW-I	**0.42±0.12**	**4.18±1.13**	**7.48±1.56**
Yuragi-B	0.29±0.10	2.61±1.01	5.20±1.53
ELW-II	**15.02±2.14**	**126.50±11.32**	**9.58±0.58**
Yuragi-A	8.98±2.38	64.40±14.50	6.03±1.30
ELW-III	**39.93±4.78**	**372.39±42.00**	**9.95±0.21**
Yuragi-B	24.07±4.48	180.59±29.03	6.07±1.48
ELW IV	**0.39±0.01**	**3.83±0.97**	**6.89±0.97**
Yuragi-A	0.35±0.13	3.03±1.12	4.45±1.37
ELW V	**6.22±0.85**	**56.71±7.13**	**9.73±0.48**
Yuragi-A	3.93±0.99	29.91±6.67	6.19±1.41

RESULTS

CROSS-TESTING OF ELW PARAMETERS ACROSS ENVIRONMENTS.

Search Behaviour	Metric	Environment I	Environment II	Environment III	Environment IV	Environment V
ELW-I	Efficiency (10^{-2})	0.42±0.12	10.09±1.74	20.64±2.63	0.37±0.15	4.40±0.81
	Rewards Found (10^{2})	4.18±1.13	72.70±9.97	124.68±12.17	3.59±1.30	34.00±5.42
	Patches Found	7.48±1.56	6.01±1.04	3.91±1.73	5.18±1.62	6.83±1.17
ELW-II	Efficiency (10^{-2})	0.40±0.10	15.02±2.14	38.81±3.74	0.38±0.11	6.17±0.92
	Rewards Found (10^{2})	3.92±0.99	126.50±11.32	266.51±18.25	3.73±1.05	55.92±7.74
	Patches Found	7.27±1.43	9.58±0.21	8.59±1.08	7.08±1.38	9.80±0.47
ELW-III	Efficiency (10^{-2})	0.24±0.07	9.98±1.73	39.93±4.78	0.21±0.07	3.82±0.64
	Rewards Found (10^{2})	2.36±0.69	98.12±16.84	372.39±42.00	2.18±0.78	37.82±6.35
	Patches Found	7.56±1.32	9.85±1.03	9.95±0.21	7.10±1.57	9.93±0.32
ELW-IV	Efficiency (10^{-2}	0.41±0.10	12.92±2.02	38.22±3.46	0.39±0.01	5.20±0.79
	Rewards Found (10^{2})	4.16±0.95	113.35±15.87	276.95±18.67	3.83±0.97	48.12±6.85
	Patches Found	7.32±1.29	9.87±0.37	9.49±0.67	6.89±1.29	9.85±0.36
ELW-V	Efficiency (10^{-2}	0.36±0.11	15.01±1.87	39.01±3.61	0.35±0.11	6.21±0.85
	Rewards Found (10^{2})	3.60±1.12	127.10±13.51	274.55±17.48	3.56±1.11	56.71±7.13
	Patches Found	6.98±1.50	9.66±0.55	8.87±0.87	7.12±1.45	9.73±0.46
Yuragi-A	Efficiency (10^{-2})	0.26±0.11	8.98±2.38	19.74±3.51	0.35±0.13	3.93±0.99
	Rewards Found (10^{2})	2.01±1.01	64.40±14.51	121.61±16.64	3.03±1.12	29.91±6.67
	Patches Found	4.81±1.16	6.03±1.31	3.86±1.4	4.45±1.37	6.19±1.41
Yuragi-B	Efficiency (10^{-2})	0.29±0.10	7.41±1.98	24.07±4.48	0.29±0.11	3.19±0.89
	Rewards Found (10^{2})	2.61±1.01	61.80±15.68	180.59±29.03	2.58±0.95	27.17±7.29
	Patches Found	5.20±1.53	7.19±1.41	6.07±1.48	4.85±1.45	7.43±1.65

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Conclusions

- We presented an artificial endocrine approach to modulate Lévy Walk behaviour in adaptive foraging tasks in patchy environments.
- ELW outperforms the Yuragi approach in all scenarios tested, even when not optimized specifically for that scenario.

Future Work

- Perform analysis on the trajectory and how well it fits to the predicted Lévy Walk model
- Deploy that strategy on an autonomous drone (Crazyflie)
- Compare efficiency from an energy perspective

THANK YOU!

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