On The Role of the Multi-Level and Multi-Scale Nature of Behaviour and Cognition

Stefano Nolfi
Laboratory of Autonomous Robotics and Artificial Life
Institute of Cognitive Sciences and Technologies, CNR
Roma, Italy
http://laral.istc.cnr.it/nolfi/
stefano.nolfi@istc.cnr.it
Behavior and cognition are dynamical process with a multi-level and multi-scale organization.
How the behaviour of adaptive robots typically have a multi-level and multi-scale organization

1. How the interaction between lower-level behaviours enable generalizations at the level of behaviour

2. How existing behavioural skills can establish the conditions for the development of new higher-levels skill

3. How the multi-level and multi-scale organization of behaviour enable compositionality and behaviour generalization
1. How the interaction between lower-level behaviours enable behaviour generalizations
Evolving coordinated locomotion in self-assembled Swarm-Bots

Denebourg, Dorigo, Floreano, Gambardella, Mondada, Nolfi, 2002-2004

[2022] Baldassarre, Trianni, Bonani, Mondada, Dorigo, Nolfi, 2006

coordinated motion
Robots generalize with respect to:

1) The number of assembled robots
2) The shape of the swarm-bot
3) The type of links

Display additional behavioral capabilities:

1) Collective obstacle avoidance
2) Collective object-pushing pulling
3) Dynamical shape re-arrangement
The multi-level structure of the behavior displayed by the robots

- Collective navigation
- Exploration
- Coordinate motion
- Conformistic behavior
- Obstacle avoidance
- Phototaxis
- Move forward behavior
- Coordinate light approaching
- Dynamical shape re-arrangement

[Nolfi, in press]
2. How the development of behavioral skills establish the conditions for the development of new higher-levels skills
Evolution of behavioral and communication skills in groups of cooperating robots

**Fitness Function:** The group is reward with 1 point every time the robots are concurrently located in the two areas for the first time or after a switch

De Greef & Nolfi, 2010
Summary of the main evolutionary progresses

- Infrared-off -> move-forward
- Infrared-on -> avoid-obstacles
- move-f. & avoid-ob. -> find areas
- ground-black -> remain on the black area look-robot-and-follow-border
- ground-white/black -> signal A/B
- Sound-B & ground-black -> exit from black area
- Sound-A & ground-white -> remain on white area follow border
- Sound-B & ground-white & see-robot -> exit from white area toward the other robot
- exit from white & move-f -> navigate-to-black
- look-r.-follow-b. & & move-f -> navigate-to-white

New higher-level capacities emerge through the interactions between pre-existing skills or through new traits combined with skill re-use.

Innovations are enabled by the new adaptive opportunities created by the effects of agents’ behaviors and by the possibility to re-use existing capacity.

Established skills (assuming new functions) tend to be preserved thus leading to an incremental process and to a complexification of agents skills.

Language and action integration and synergies between language and action development

Signals are grounded in behavioral skills.

The ‘meaning’ of a signal is constituted by the action/s triggered by the signal in a specific context.

3. How the multi-level and multi-scale organization of behavior enable compositionality and behavior generalization
Fitness: The robot is rewarded for the ability to realize the goals of the experienced utterances.

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<tr>
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<td>NO</td>
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<tr>
<td>MOVE</td>
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</tbody>
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Tuci, Ferrauto, Zeschel, Massera, Nolfi (2009, 2011)
Development of early language comprehension capabilities

Ferrauto and Nolfi (2012)

- Indicate red
- Touch yellow
- Grasp red
By post-evaluating the robots at the end of the training process with observed that some of them display an ability to comprehend the two new utterances by displaying the corresponding appropriate behaviors.

Robots trained to produce related skills tend to lead to solutions based on multi-level organizations supporting skill re-combination and re-use.

Tuci, Ferrauto, Arne, Massera, Nolfi (2010, 2011)
thank you for your attention