Simulating the acquisition of numerical concepts in embodied agents

General framework and proposals
Insights from cognitive psychology

• Humans possess two complementary abilities that are useful to manipulate quantities (and, very likely, to learn mathematics)

1. We can efficiently estimate the numerosity of a set, for example by guessing how many objects are contained in a visual scene
   • This is a very fast process (requires just few hundreds of milliseconds)
   • However, it results in approximate estimations

2. We can precisely establish the cardinality of a set
   • For large sets (n > 5) this requires the deployment of slow counting procedures
   • However, it usually return the exact number
Simulating the approximate number system

- It has been shown that approximate representations of numerosity can emerge from unsupervised deep learning
  - Deep networks can accurately simulate human judgments in numerosity discrimination tasks
  - Artificial neurons often exhibit tuning functions resembling those recorded in biological neurons

Stoianov and Zorzi (2012) *Nature Neuroscience*
Zorzi and Testolin (2018) *Phil. Trans. of the Royal Society B*
But how to move from approximate to exact numbers?

• We could mimic the learning processes occurring in children!

• Finger counting might allow to acquire exact number representations
  • Finger configurations enable to establish invariant representations
    (e.g., counting 8 apples or 8 birds will result in the same configuration)
  • “Embodiment” allows to exploit the physical dynamics of our own body to facilitate the deployment of counting procedures
    (e.g., incrementally keeping track of numbers)
Developmental Cognitive Robotics

• Some preliminary work has been recently carried out using the iCub robotic platform

• However, experiments have not been systematically compared with children behavior

• Moreover, deep learning could help in boosting the performance of the counting robot