Titolo: Neuromorphic cyber-physical systems

Spiking Neural Networks (SNNs) are strongly bio-inspired—also referred to as neuromorphic—neural models that process information in the form of discrete events (spikes). They are considered effective alternatives to conventional artificial neural networks for handling real-time, sparse data streams produced by event-based sensors, such as cameras or other asynchronous sensing modalities. These sensors are increasingly adopted in autonomous cyber-physical systems (CPS), including robots, drones, vehicles, and human–machine interfaces (HMIs).

Beyond their intrinsic energy efficiency, SNNs are attracting growing research interest due to their capability for online and continual learning without relying on backpropagation or large replay buffers, unlike their artificial counterparts. This property is particularly valuable for autonomous CPS operating in highly dynamic and heterogeneous environments, where adaptability and resource efficiency are critical.

Currently, most implementations of continual learning in SNNs are confined to specialized neuromorphic platforms, such as Intel Loihi or SpiNNaker (see CLP-SNN), and are typically evaluated on relatively simple benchmarks. Porting these approaches to a general-purpose, ultra-low-power, open-source microcontroller architecture and assessing their performance on more realistic robotics benchmarks would significantly broaden their applicability to open-hardware autonomous CPS.

2. RESEARCH ACTIVITY AND PLAN (Attività e piano di ricerca)

(ENG)

The activity will focus on: i) becoming familiar with neuromorphic continual learning algorithms like Continual Learning Prototypes (CLP) in Python; ii) re-implementing CLP-SNN in Python and evaluate it on perception tasks; iii) implementing real-time continual learning mechanisms for SNNs on a PULP-based microcontroller architecture (GAP9), such as the one used in the Bitcraze Crazyflie microdrone. The student will identify the most suitable neuromorphic continual learning strategy and port it to the target GAP9 platform. The proposed evaluation benchmarks will target robotics perception tasks, including optical flow estimation and visual–inertial odometry (VIO).

Activities will be developed within the ROBOMIX2 project.

(ITA)

L'attività si concentrerà su: i) familiarizzare con algoritmi di apprendimento continuo neuromorfico come Continual Learning Prototypes (CLP) in Python; ii) re-implementare CLP-SNN in Python e valutarlo su compiti di percezione; iii) implementare meccanismi di apprendimento continuo in tempo reale per SNN su un'architettura di microcontrollore basata su PULP (GAP9), come quella utilizzata nel microdrone Bitcraze Crazyflie. Lo studente individuerà la strategia di apprendimento continuo neuromorfico più adatta e la adatterà alla piattaforma GAP9 di destinazione. I benchmark di valutazione proposti riguarderanno compiti di percezione robotica, tra cui la stima del flusso ottico e l'odometria visuo-inerziale (VIO). Le attività saranno svolte nell’ambito del Progetto ROBOMIX2