conTorchionist: a flexible nomadic library for exploring machine listening/learning in multiple platforms, languages, and time-contexts

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machine listening: contexts and meanings

- *machine listening* in *Interactive Music Systems*: initially, meaning to the process of 'listening to' MIDI parameters
- in MSP/PD context: real-time audio feature extraction and analysis
- 2000s: increasingly influenced by the *machine listening* meaning from related fields like Music Information Retrieval (MIR), Automatic Speech Recognition (ASR), and Computational Auditory Scene Analysis (CASA)
- today, in a broader context:
  strongly transformed by the widespread adoption of machine learning (ML)/artificial intelligence (AI)/deep learning (DL) techniques
- from a critical-exploratory-creative perspective: integration of these techniques into artistic and research practices is still challenging.

challenges

- **pragmatic/end-user** design: many tools are designed for very specific purposes (e.g., stem separation, timbre transfer, etc.) but not for general exploration.
- **'black box'**: many modern tools function as opaque "black boxes", limiting creative exploration and understanding, segregating people into "users" and "developers".
- **isolation** into environment/language, OS, architecture, and/or time-context: many tools are tied to a specific environment/language, OS, architecture or time-context, restricting workflows (e.g.: train in non-real-time, use/apply in real-time; usage of different tools in musicological and creative contexts; etc.).
- **CPU-only**: most tools do not leverage **GPU** acceleration, while this is widely used in other AI/ML fields.

conTorchionist goals

- **flexibility**: allow for use the same machine listening/learning in different contexts (real-time/non-real-time; environments/languages; OS/architectures; CPU/GPU; etc)
- **nomadic**: allow for easy migration/integration of workflows and models between different environments/languages (PD, Max, SC, Python, etc.)
- **transparent**: provide access/manipulation of the inner workings of the DSP/ML algorithms
- **torch-based**: take advantage of the open-source PyTorch/libtorch/torchaudio ecosystem, which is widely used in the AI/ML community
- **core/wrappers architecture**: a single C++ core shared library (relying on `libtorch`) with language-specific wrappers for different environments (PD, Max, SC, Python, etc.)

remarkable and inspiring projects

- **Librosa (Python):** The most popular Python library for Music Information Retrieval (MIR), offering a vast range of tools for audio analysis.
- **Essentia (C++/Python):** A C++ library with Python bindings, prioritizing efficiency and scalability for both real-time and non-real-time processing.
- **timbreID (Pure Data), Zsa.Descriptors (Max), SCMIR (SuperCollider):** Real-time audio feature extraction libraries tailored to their respective environments.
- **FluCoMa (Fluid Corpus Manipulation):** A comprehensive C++ toolset for Max, Pure Data, and SuperCollider, enabling both real-time and non-real-time corpus-based workflows. **(a great inspiration for this work)**
- **nn_tilde:** A direct bridge for running pre-trained PyTorch models (inference) in real-time environments like Max and Pure Data (with a port for SC), demonstrating the demand for this specific integration.
- **PyTorch / libtorch / torchaudio:** The foundational ML ecosystem. It provides powerful tensor computation on CPU/GPU and the core C++ backend (`libtorch`) that makes **conTorchionist** possible.

architecture overview

A simple, two-part structure:

- **core library (C++)**
  - Relying on `libtorch` (the C++ core of PyTorch).
  - Built as a shared library (`.dylib`, `.so`, `.dll`).
  - Contains all core algorithms (`Processors`) for audio analysis, ML, etc.
  - Platform-agnostic.
- **Wrappers**
  - Language-specific bindings for PD, Max, SC, and Python.
  - Use language-specific APIs, utilities, and auxiliary headers to interface with the core library.
  - Handles the instantiation and management of `Processors` in the target environment.

core / processors

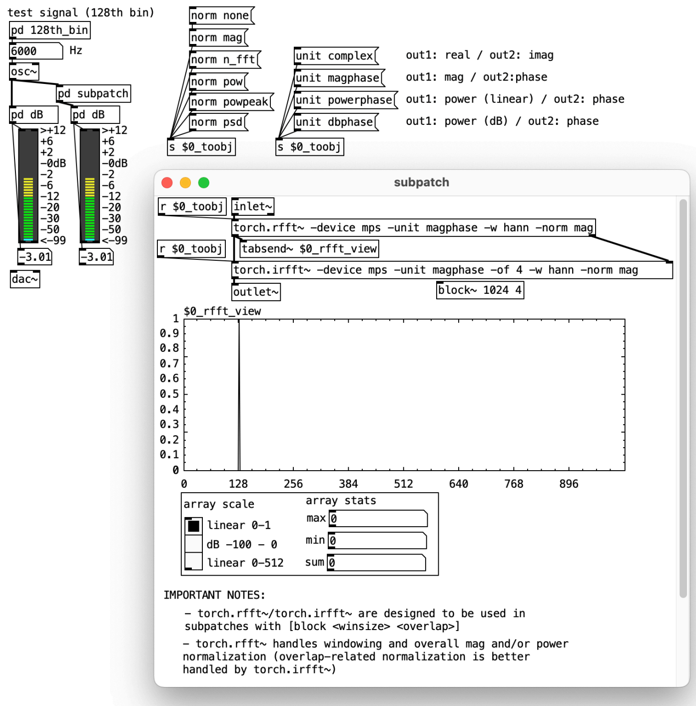
A set of modular tools for signal processing, designed for high performance and customizability.

Some implemented `Processors`:

- `RMSOverlapProcessor`: RMS with different windowing/interpolation options, using a circular buffer (actually also a processor) to handle overlapping frames.
- `RFFTProcessor` / `IRFFTProcessor`: Real and Inverse Fast Fourier Transform.
- `SpectrogramProcessor`: Real-time spectrogram computation.
- `MelSpectrogramProcessor`: Maps frequency to the Mel scale.
- `MFCCProcessor`: Extracts Mel-frequency cepstral coefficients.

example 1: `torch.rfft~` and `torch.irfft~` in Pure Data

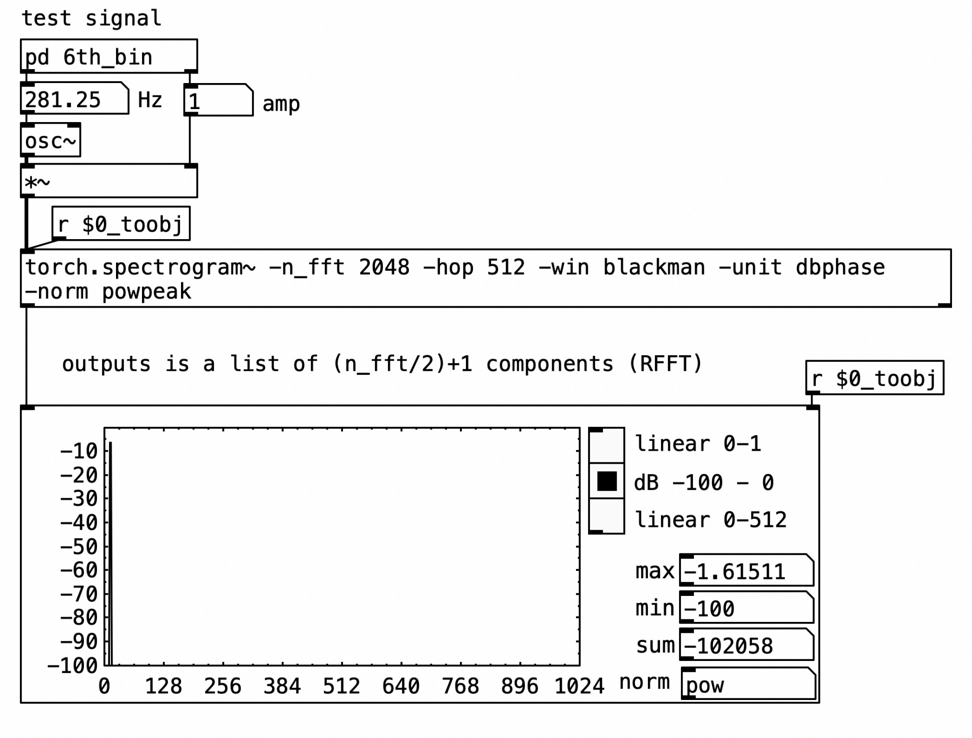
The RFFTProcessor and IRFFTProcessor exposed as the [torch.rfft~] and [torch.irfft~] objects, respectively. They allow for real-time, GPU-accelerated FFT analysis directly within the patching environment.



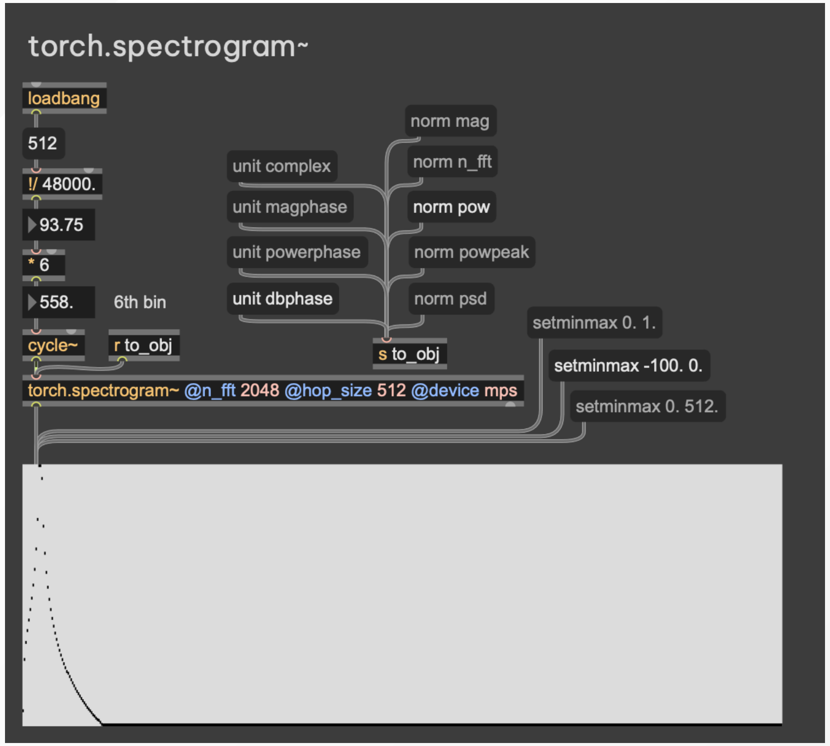
torch.rfft~ and torch.irfft~ / Pure Data

example 2: `torch.spectrogram~` in Pure Data & Max

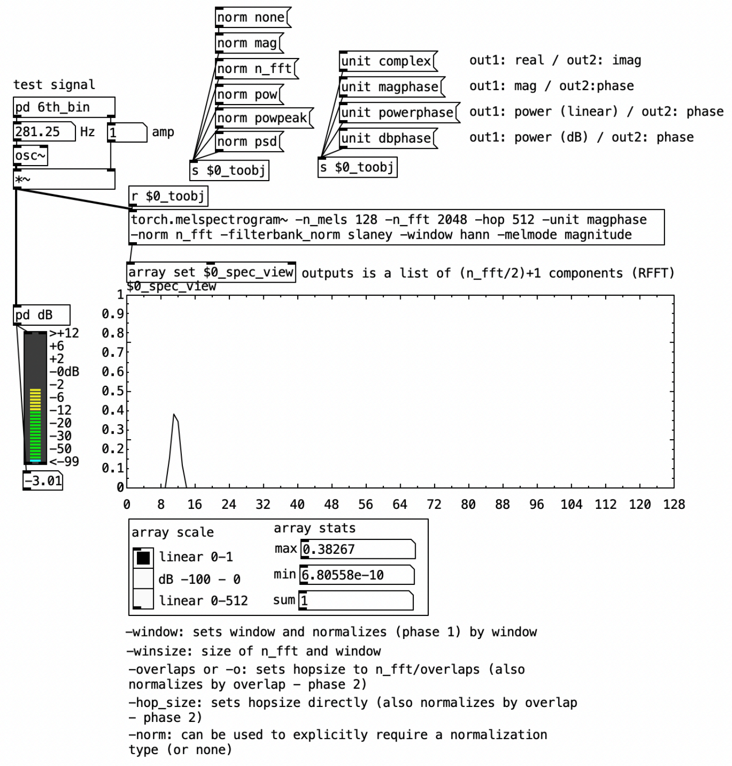
The SpectrogramProcessor is exposed as the [torch.spectrogram~] object. It allows for real-time, GPU-accelerated spectrogram analysis directly within the patching environment.



torch.spectrogram~ / Pure Data



torch.spectrogram~ / Max



example 3: Mel spectrogram in Pure Data

The MelSpectrogramProcessor is exposed as the [torch.melspectrogram~] object. It allows for real-time, GPU-accelerated Mel spectrogram extraction directly within the patching environment.

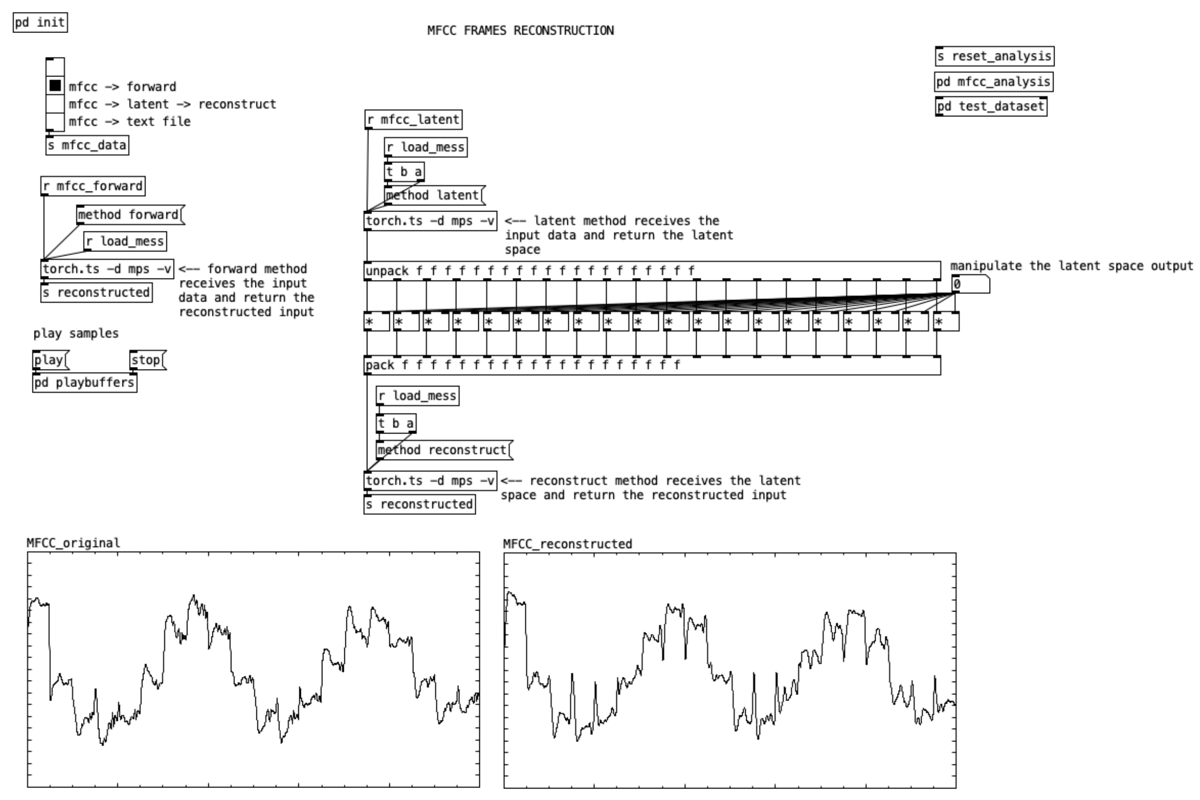
neural network processors

`conTorchionist` supports two main approaches for integrating neural networks:

- **Inference:** Load and run complex, pre-trained models (from Python/PyTorch) in real-time using the `[torch.ts~]` object.

- **Interactive Model Building:** Create, train, and explore simple neural networks directly within the environment (e.g., Pure Data) using modular objects/processors (`[torch.sequential]`, `[torch.linear]`, `[torch.activation]`, etc.).

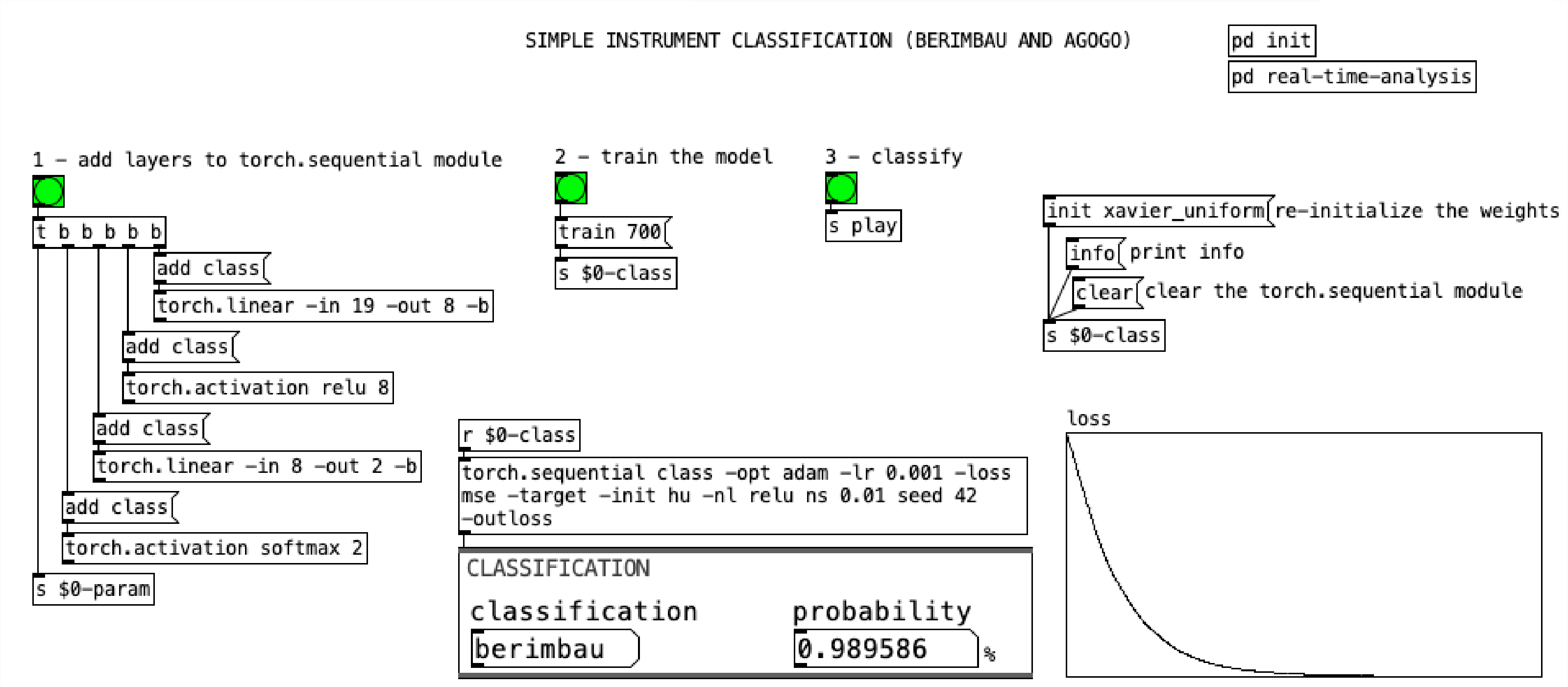
example 4: loading a pre-trained model



The [torch.ts] object can load a TorchScript model (`.ts`) to perform tasks like real-time audio synthesis or, in this case, MFCC frame reconstruction using an autoencoder.

example 5: building a network in pure data

The [torch.sequential] object acts as a container, allowing you to build a neural network layer by layer using other objects like [torch.linear] and [torch.activation]. This transforms the environment into an exploratory space for prototyping models.



conclusion and future work

- development is at an early stage, with many features yet to be implemented (expand set of Processors, implement more wrappers, etc.)
- the library is open-source (LGPLv3) and available at [https://github.com/ecrisufmg/contorchionist]
- binary releases to be made available when we have the current Processors wrappers implemented and documented

final remarks / acknowledgments

- `conTorchionist` was made with the support of FAPEMIG, CAPES, and CNPq.
- AI agents and tools were used while sketching and writing some parts of `conTorchionist` (usually requiring a lot of corrections and adaptations)

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thanks!

code:
https://github.com/ecrisufmg/contorchionist

examples:
https://www.youtube.com/watch?v=4R0uCS_r9QA
https://www.youtube.com/watch?v=0PbWdBhGKzk
https://www.youtube.com/watch?v=AbU6onIZAO8

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