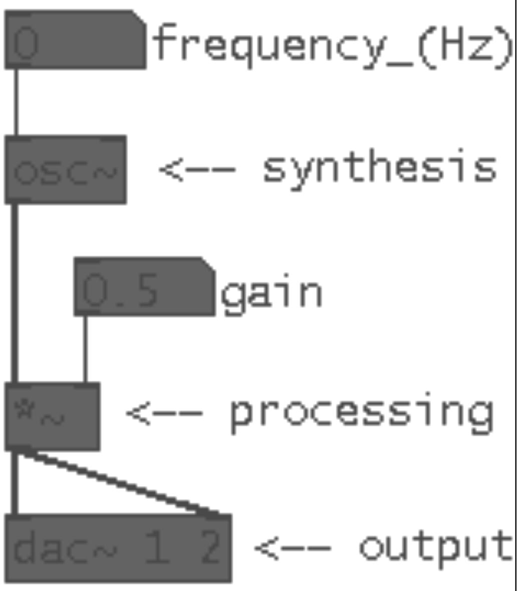
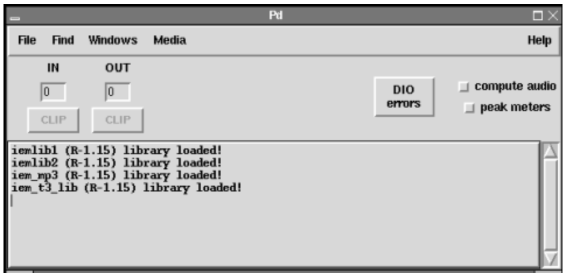
Introduction to Pure Data



Pure Data

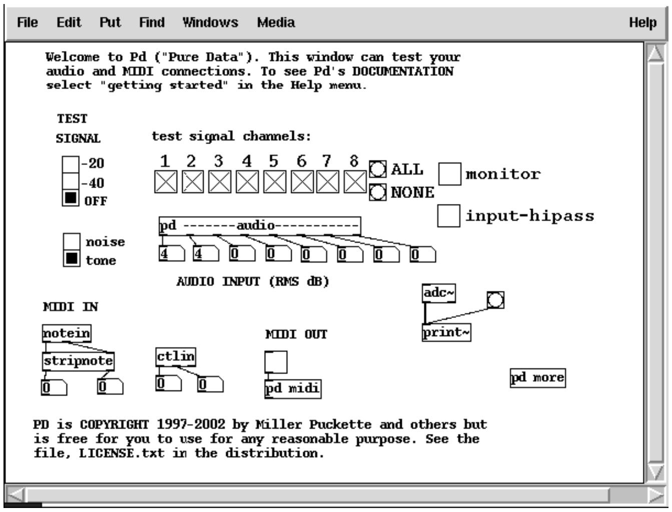
- Pure Data (Pd) is a visual signal dataflow programming language
- Designed to process sound and MIDI events. Has grown to process video and inputs from a variety of general purpose sensors
- Free alternative to MAX/MSP
- Runs on Linux, Macintosh, and Windows computers

Pure Data Console



```
iemlib1 (R-1.15) library loaded!
iemlib2 (R-1.15) library loaded!
iem_mp3 (R-1.15) library loaded!
iem_t3_lib (R-1.15) library loaded!
```

Pure Data Test Signal



Welcome to Pd ("Pure Data"). This window can test your audio and MIDI connections. To see Pd's DOCUMENTATION select "getting started" in the Help menu.

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2.2 How does Pure Data work?

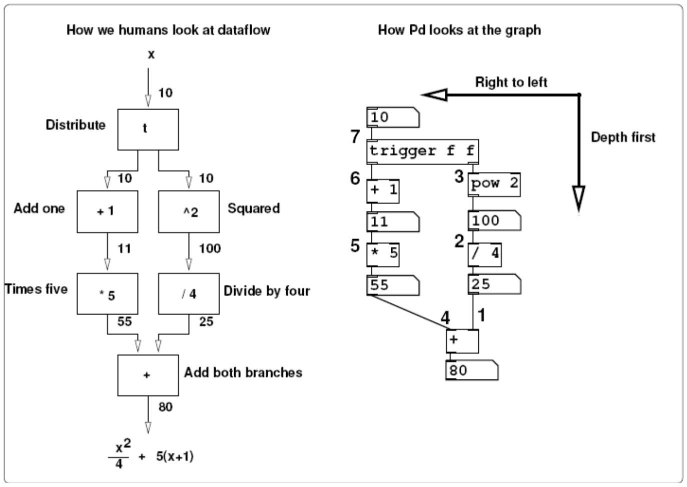
- Data flows between objects connected through cords or wires
- Thin cords carry message data; fat cords carry audio signals
- Objects take in data at inlets, and may send output to outlets; inlets and outlets appear as tabs at the edge of objects
- Types of object names:
  - Object names with ~: Process signals
  - Object names without ~: Process messages

Like a Moog™ modular synth, but digital

Patches

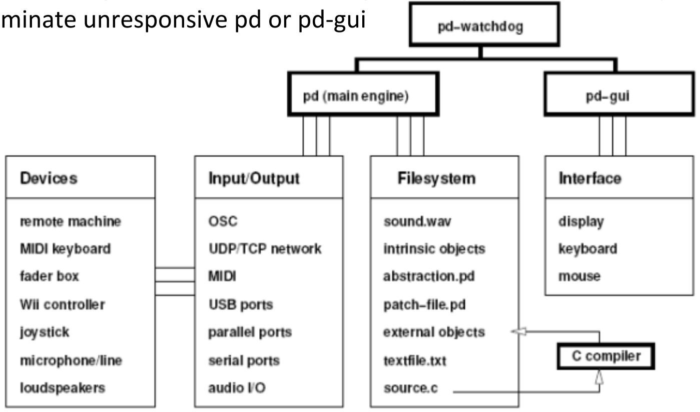
- A collection of objects wired together is a dataflow graph program or *patch*. Name is derived from analog electronic synthesizer modules connected together with patch cords
- Patches are placed on a *canvas*
- Patches are navigated by the PD interpreter depth first, from right to left (tries to go as deep as possible in a graph, processing the right-most branch first before a left branch)

Dataflow computation

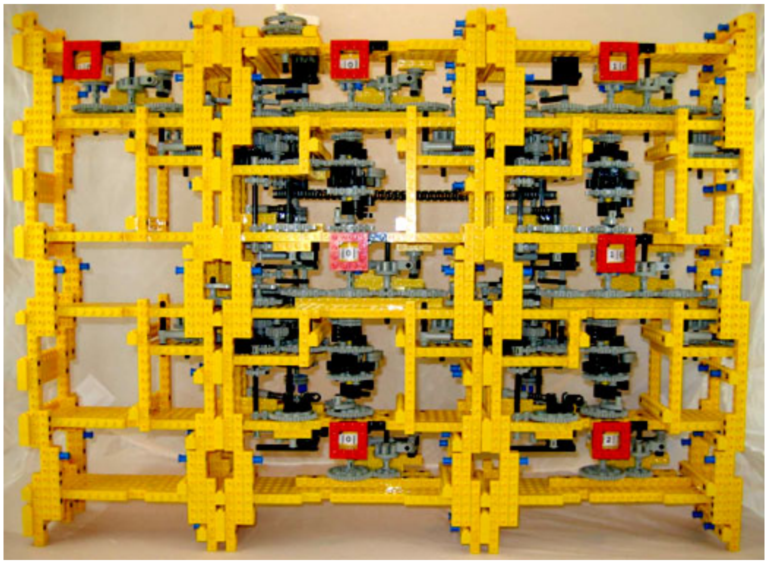


Pure Data Software Architecture

- Pure Data consists of several programs:
  - pd(main engine): the interpreter, scheduler and audio engine
  - pd-gui: the interface you use to build Pure Data programs
  - pd-watchdog: monitors the main engine and gui, and will attempt to terminate unresponsive pd or pd-gui

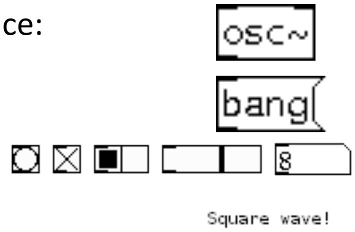


LEGO® for sound and video?



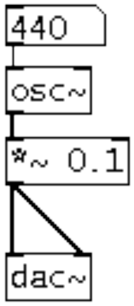
Pd basic elements (1)

- Object types by function/appearance:
  - Object (processing)
  - Message (events)
  - GUI (user interaction)
  - Comment (documentation)
- Object types by topology:
  - Source (outlet only)
  - Sink (inlet only)
  - Filter (inlet and outlet)
- Atoms
  - Float, symbol or pointer



Pd basic elements (2)

- Patch = network or graph of data flows
- Connections/Streams:
  - Signals (continuous audio)
  - Messages (sporadic events)
    - Typ. control-oriented
    - Made up of multiple atoms
  - Data streams flow from top to bottom
- Audio I/O: [adc~], [dac~]
- Abstraction
- Editing and Interaction modes



Origins

- Miller S. Puckette
  - PhD in math from Harvard in 1986
  - Currently at CRCA (Center for Research in Computing and the Arts), UCSD
- IRCAM (FR) (1980s) Institut de Recherche et Coordination Acoustique/Musique
  - Was common for technicians to develop systems to support artists
  - Puckette developed Max to enable artists to do it themselves
- Pure Data (Puckette, 1996)
  - Design based on Max
  - Open source
  - New: graphical data structures

Pd's philosophy and architecture

- Graphical literate programming:
  - Visual appearance of the patch **is** the program
  - DSP block diagrams are pseudocode
  - Comment objects can be placed anywhere on a patch
- Object-oriented/functional paradigm:
  - Classes and instantiation
  - Message passing
  - Outlets pass data to inlets
- Patch = document = program/subprogram
- Object network must be acyclic
  - But feedback (recirculation of data) is possible using special delay objects
- Data processed in real time

Other design features

- Patches can be edited while running
- Abstraction and re-use of patches
  - *Ad hoc*, one-off sub-patches
  - External patches (re-usable)
  - All look like objects from the outside
- Data structures: arrays, lists, graphics
- Entire libraries of "externals"
- Help file conventions make objects self-documenting

Implementation details

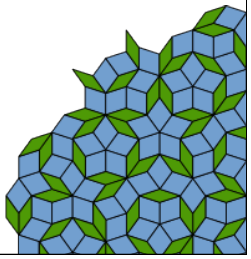
- All numbers are 32-bit floating-point
  - Audio h/w usually 16-24 bit integer precision
- Primitive objects typ. implemented in C
- Many audio APIs supported:
  - PortAudio, ASIO, MMIO, Core Audio, ALSA, OSS, JACK
- Audio rate processing runs continuously, in blocks
  - Usually driven by audio hardware clock
- Patches stored as plain text, describing topology and layout
- GUI is implemented using Tcl/Tk

Input/Output

- [print], [snapshot~]
- Load/save audio files to/from Pd arrays
- MIDI, OSC
- USB HID-class devices: [hid]
  - Keyboard, mouse, joystick, etc.
- Bluetooth (e.g. Wii™ remote control)
- Network (TCP or UDP)
  - Messages and uncompressed audio
  - Compressed audio, e.g. [oggcast~]
- Local IPC: pdsend/pdreceive
- COMEDI (Linux)
- Video capture

Subtleties

- Using messages for control of audio-rate data
  - Quantisation, low data rate (10-1000 Hz)
  - "Zipper noise", clicks on toggling, noise
  - Add interpolation ([line], [line~], [vline~])
- Foldover distortion (sampling; Nyquist limit)
- Clipping on audio I/O
- NaN
- Platform-dependent features:
  - Graphics, codecs, tablets, etc.



Thinking in data flows

- Where are the loops? Conditionals? Variables? Assignment operations? Flow of control?

No visible flow of control

- Messages happen virtually simultaneously
- Audio signals processed continuously…
  - But in finite blocks
    - Power-of-2 samples in duration
    - Some latency (1.45 ms typ. @ 44.1 kHz)
    - Interleaved with message processing
- Implicit event loop, effectively
- However, it's not stateless…

Some procedural counterparts

- Variables (typed)
  - [integer], [float] and [symbol]
  - Store received input values, emit when "banged"
- [until] for iteration
- Expressions
  - Network of objects (inverted expression tree)
  - [expr] (formula in a box)
- [spigot] conditionally enables data flow
- [moses], [select] and [route] resemble CASE or IF as functions
- Numeric messages can be interpreted as Booleans
- Objects for logical and relational operators
  - [&&], [||], [==], [<], [<=], et al.

Certain tasks are easier in a data-flow environment

- Real-time, interactive tasks
- Function-oriented tasks
- Dealing with continuous signals (streams)
  - e.g. capture and playback, analysis and synthesis
- Event-driven stuff
  - External triggers, physical devices
  - Timed events (e.g. [metro] (metronome))

Going beyond sound

- 3D: GEM (OpenGL)
- Video capture, processing, compositing, etc.
  - PDP, PiDiP
- Physical modelling
- Physical transducers and other I/O

Light sensors

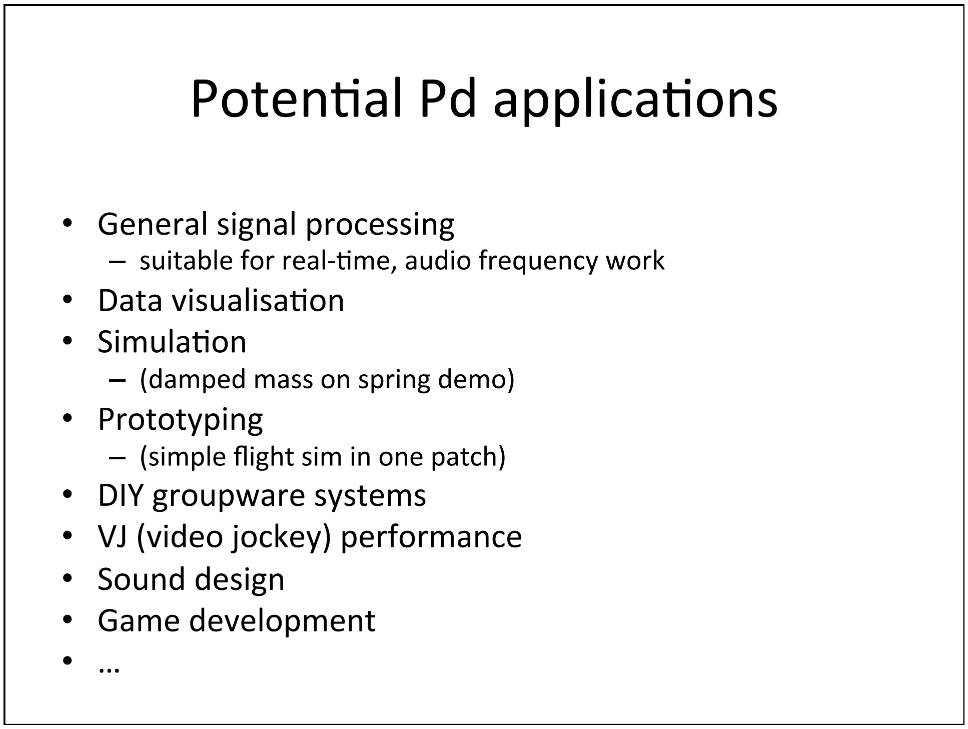
- Ordinary cadmium sulfide devices
- More light, less resistance
- Some analog pre-processing required before DAC

Drum pads

- Rubber practice pads
- Piezoelectric transducer element
- Suitable for use with Pd’s [bonk~] object
  - Takes audio signal as input
  - Detects “hits”
  - Outputs messages (including intensity)

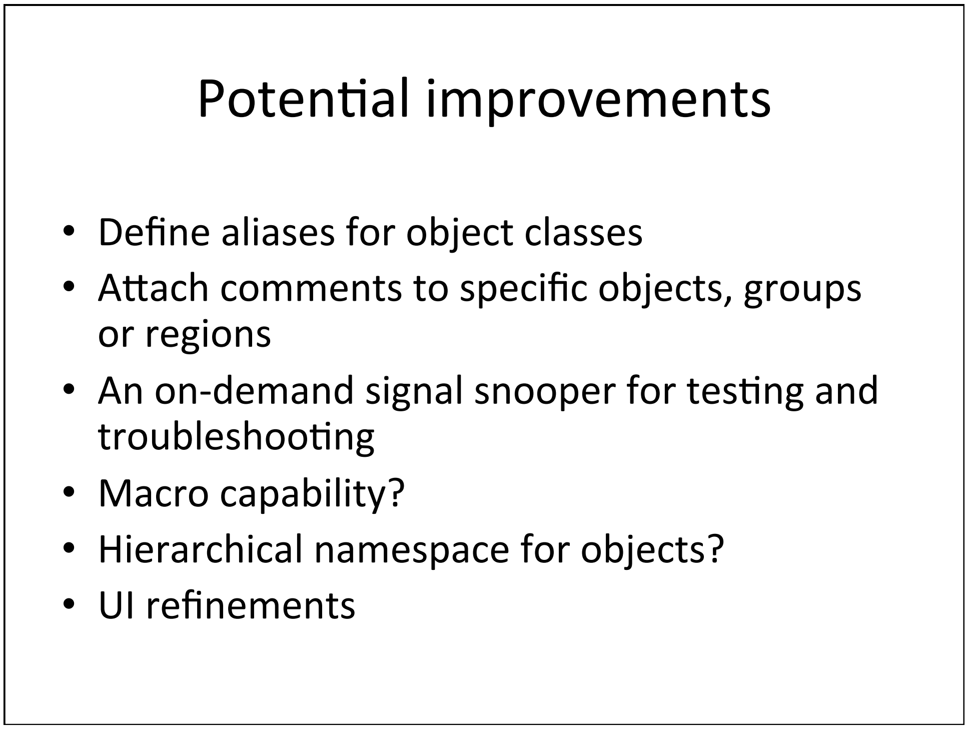
Wii™ remote controller

- Buttons
- 3-axis accelerometer
- IR camera for tracking reference points
- Vibration
- Speaker
- LEDs



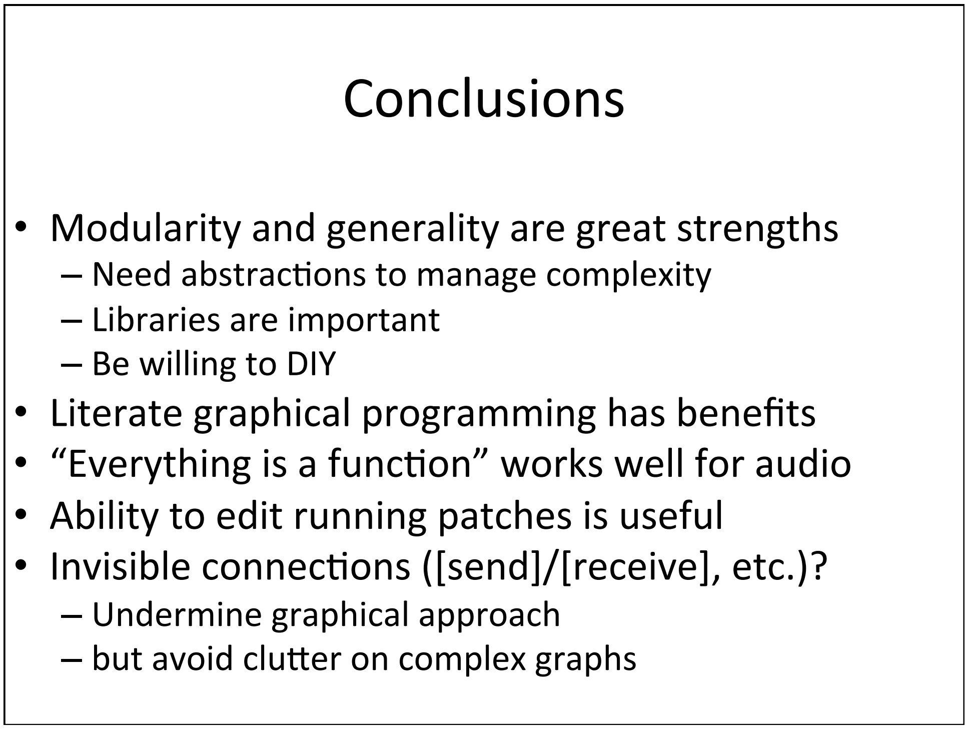
Potential Pd applications

- General signal processing
  - suitable for real-time, audio frequency work
- Data visualisation
- Simulation
  - (damped mass on spring demo)
- Prototyping
  - (simple flight sim in one patch)
- DIY groupware systems
- VJ (video jockey) performance
- Sound design
- Game development
- …



Potential improvements

- Define aliases for object classes
- Attach comments to specific objects, groups or regions
- An on-demand signal snooper for testing and troubleshooting
- Macro capability?
- Hierarchical namespace for objects?
- UI refinements



Conclusions

- Modularity and generality are great strengths
  - – Need abstractions to manage complexity
  - – Libraries are important
  - – Be willing to DIY
- Literate graphical programming has benefits
- “Everything is a function” works well for audio
- Ability to edit running patches is useful
- Invisible connections ([send]/[receive], etc.)?
  - – Undermine graphical approach
  - – but avoid clutter on complex graphs