Minimalist beamline control and experiment software

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Introduction

Efforts are being made at the High Energy Photon Source (HEPS) to systematically approach the complexity lower-bounds both in beamline control (DOI: `10.1107/S160057752200337X`) and in experiment software (DOI: `10.1107/S1600577522002697`). This poster gives some representative results, and highlights additional examples which the author believes to have satisfactorily approximated the complexity lower-bounds in certain aspects.

Minimalist beamline control

Our packaging system (GitHub: **`ihep-pkg-ose`**) creates highly reproducible packages for EPICS modules covering the full synApps collection, with support for Rocky Linux 8 added recently. With our Python-assisted inheritance and metadata generation system, adding an EPICS module to our collection is often as simple as is shown below, from which the author believes the complexity lower-bound in EPICS packaging is satisfactorily approximated.

```
# Apart from this .spec file, corresponding entries also need to be added
# to misc/SHA512SUMS/main and misc/pkgs/epics (one-line change for each).
%define repo ADmarCCD
%define commit 8f62ac54
%{meta name license=EPICS github=areaDetector version=2_3,2.commit}
Summary:        EPICS - Rayonix MarCCD detectors
%{inherit ad + deps}
%description
%{inherit ad}
```

EPICS applications involving multiple support modules are traditionally implemented by self-built IOC executables that depend on these modules, but a majority of them can also be done by using multiple single-module IOCs simultaneously. Along with the support modules, provided in our packages are reusable modular IOCs that can be fed with application-specific **`cmd`**s, **`db`**s and ancillary data, which we conventionally put in **`~/iocBoot`** (see below). With extensive use of these IOCs, we can dramatically reduce the need for self-built IOCs, reducing the workload in creating and maintaining the corresponding applications by 1–2 orders of magnitude. This also enables highly maintainable accommodation of most IOCs on a beamline on just a few computers with very modest hardware.

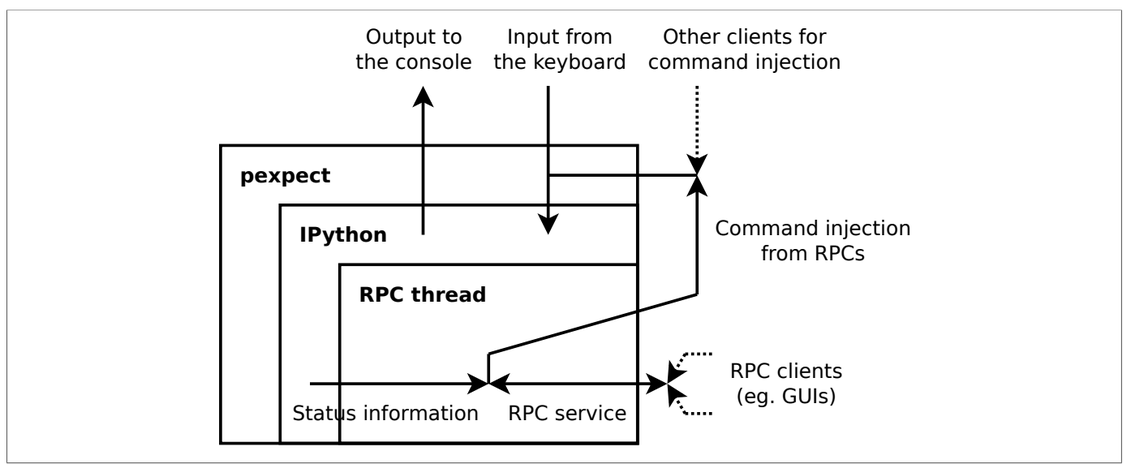
```
#!/bin/sh -e
# Loads config from ${HOME}/iocBoot/${IOC} instead of ${TOP}/iocBoot/${IOC}.
cd /opt/epics/StreamDevice/iocBoot/iocThermo
exec ../../bin/linux-x86_64/streamApp ~/iocBoot/iocThermo/temp18c.cmd

#!/bin/sh -e
# Useful supports, like autosave and iocStats, are added to reusable IOCs.
cd ~/iocBoot/iocSoft
exec softIoc -m 'C=BL3W1:,M=mono:,SCAN=1 second,IOC=BL3W1:Stats:mono:' \
    -d mono.db -d /opt/epics/iocStats/db/iocAdminCore.db

#!/bin/sh -e
# Subdirectories under `iocs' are moved to ${SUPPORT} automatically by
# the packaging system for all motor and areaDetector modules, so no more
# /opt/epics/areaDetector/ADXspress3/iocs/xspress3IOC/iocBoot/iocXspress3.
cd /opt/epics/xspress3IOC/iocBoot/iocXspress3
exec ../../bin/linux-x86_64/xspress3AppQD ~/iocBoot/iocXspress3/st.cmd
```

Efforts are also made to simplify EPICS modules' codebases. For example, the module for Xspress3 contains a lot of code duplicated for each (number of boxes, number of channels) combination configured upstream, most of them generated with the **`iocbuilder`** utility (of thousands lines of code), leading to great difficulty for an outsider to create an IOC for a new combination. The author reduced the amount of these code to a minimum that does not harm clarity (GitHub: **`ADXspress3`**); the code generator, **`xsp3-chan.sh`**, is only about 20 lines of code. A way to configure **`ADXspress3`** is shown below.

```
# Assuming the number of channels is 4.
$ mkdir -p ~/iocBoot/iocXspress3 && cd ~/iocBoot/iocXspress3
$ cp -r /etc/xspress3/calibration/initial/settings cfg-4ch
# Under xspress3IOC/iocBoot are also iocXsp3QD and iocXsp3CARS.
# By using the same technique used in refactoring code from the
# upstream, compatibility with the upstream is ensured at minimised
# cost. (A paper is being written to discuss this technique.)
$ cd /opt/epics/xspress3IOC/iocBoot/iocXspress3
$ cp st.cmd ~/iocBoot/iocXspress3
$ cd ~/iocBoot/iocXspress3 && $OLDPWD/xsp3-chan.sh 4
# Edit ~/iocBoot/iocXspress3/st.cmd: change ${XSP3CARDS}/${XSP3CHANS},
# and change the last $(TOP)/iocBoot/$(IOC) to $(HOME)/iocBoot/$(IOC).
```

Minimalist experiment software

Mamba, our beamline software framework at HEPS, uses Bluesky's **`ophyd`** for device abstraction and **`RunEngine`** for experiment orchestration. To address Bluesky's lack integrated GUIs, Mamba uses command injection and other RPCs, all based on ZeroMQ/JSON, to enable the GUIs and Bluesky-powered command line to complement each other constructively (see below). The HEPS experiment software group is also developing Mamba Data Worker (MDW), a versatile framework to implement full-fledged graphs of modular data pipes, that will meet the diverse needs in beamline experiments.



Experiment parameter generators (EPGs) are a crucial idea in Mamba, which abstract irrelevant or repetitive details on multiple levels: developers, beamline scientists, experiment users. We recently developed an EPG for PandABox-based fly scans (with a paper being written); the author believes that for fly-scan solutions of comparable flexibility, the codebase of this EPG is satisfactorily minimised. It is based on an **`ophyd`** module that implements full control of PandABox's TCP server (through **`pandablocksclient.py`** from **`pymalcolm`**) in less than 400 lines; the code below shows the sequencer table used by the EPG.

```
    table = dict([
        ("trigger", ["POSA>=POSITION", "POSA>=POSITION",
                "POSA<=POSITION", "POSA<=POSITION"]
            if pad > 0.0 else ["POSA<=POSITION", "POSA<=POSITION",
                "POSA>=POSITION", "POSA>=POSITION"]),
        ("position", [lo, hi + pad / 2, hi, lo - pad / 2]),
        ("time1", [live, 0, live, 0]), ("time2", [dead, 1, dead, 1]),
        ("repeats", [num, 1, num, 1]), ("outa1", [1, 0, 1, 0])
    ] + [(f, [0] * 4) for f in seq_outs_not(["outa1"])])
    if not snake:
        table = dict((k, [v[0], v[3]]) for k, v in table.items())
    D.panda = PandaDevice("192.168.1.11", name = "D.panda")
    D.panda.seq1.table.set(table).wait()
    print(D.panda.seq1.table.value.get())
```

Based on the **`ophyd`** module above, our EPG implements constant-speed mapping fly-scans of various dimensions in less than 200 lines, taking care of the configuration of "PandA Blocks" needed for such scans; it is also easily extensible to more advanced fly scans, like those with variable-speed or irregular trajectories. Shown first below is the Bluesky plan provided to users by the EPG, in comparison with its step-scan counterpart; underlying it are modules that can be composed by beamline scientists to implement scans deliberately fragmented to overcome hardware limits: like Xspress3's limit on the number of frames in one exposure series, or PandABox's limit on the number of sequencer entries.

```
# RE.subscribe(mdw_stepscan_callback)
# RE(grid_scan([D.xsp3, D.cnt974a], M.m2, -1, 1, 3, M.m1, -4, 4, 5))
RE.subscribe(mdw_flyscan_callback)
RE(fly_demo(0.5, M.m2, -1, 1, 3, M.m1, -4, 4, 5, period = 0.5))

# def fly_frag(panda, adp, dets, frag_gen, frag_wrap): ...
# def frag_simple(panda, div, duty, *args, period = ..., ...): ...
# def fwrap_adtrig(ads): ...
fly_demo = lambda duty, *args, **kwargs: \
    fly_frag(D.panda, D.adp, [D.xsp3],
        frag_simple(D.panda, 12216 // args[-1], duty, *args, **kwargs),
        fwrap_adtrig([D.xsp3]))

# Currently, additional settings like callbacks, metadata parameters,
# progress notification parameters are injected (or written) like
RE(fly_demo(0.5, M.m2, -1, 1, 3, M.m1, -4, 4, 5, period = 0.5,
    progress = U.progress), cb_gen("fly_demo"), md = U.mdg.read_advance())
# We are now developing further abstractions to encapsulate these code,
# so that the frontend (or the user) may simply run
P.fly_demo(0.5, M.m2, -1, 1, 3, M.m1, -4, 4, 5, period = 0.5)
```