The Belle II Analysis Software Framework

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Introduction

- Belle II Analysis Software Framework (basf2)
  - source code publicly available at https://github.com/belle2/basf2
  - documentation publicly available at https://software.belle2.org
- basf2 links against defined set of third-party libraries that we call **`externals`**
  - publicly available at https://github.com/belle2/externals
- repository with scripts to install and set up basf2 called **`tools`**
  - publicly available at https://github.com/belle2/tools
- repository with script for version managing (recommended releases and global tags)
  - publicly available at https://github.com/belle2/versioning
- LGPL (GNU Lesser General Public License) version 3 or later
  - header in each file:

> basf2 (Belle II Analysis Software Framework)
> Author: The Belle II Collaboration
>
> See git log for contributors and copyright holders.
> This file is licensed under LGPL-3.0, see LICENSE.md.

Externals

- versioned set of external software packages used and linked against the Belle II software
- dependency between packages considered and compatibility guaranteed
- C++ packages like
  - ROOT, XRootD
  - gcc, clang, gdb, cmake, Python
  - boost, Eigen, gsl
  - EvtGen, Geant4, clhep, PYTHIA
  - git, cppcheck, doxygen
- includes patches
- python packages like pandas, matplotlib, torch, tensorflow, jupyter, ...
- source files uploaded to web server to never lose availability

Tools

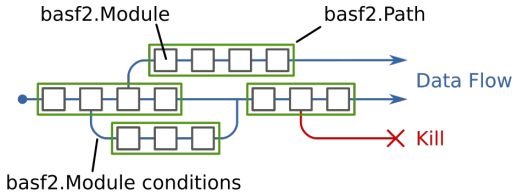
- collection of scripts to prepare environment for execution of Belle II software
- b2setup
  - setting environment variables
- b2code-create, b2code-style-check, b2code-style-fix, b2code-clean
  - creating local directory for core software development and fixing style issues
- b2install-prepare, b2install-release, b2install-externals, b2install-data
  - installing pre-compiled software versions or example data on local machine
- b2analysis-create, b2analysis-get, b2analysis-update
  - creating local directory for development of analysis code including preparation of build system and addition of repository to git

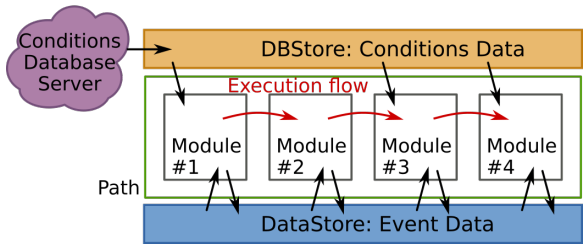
Basf2 structure

- basf2 divided into 35 packages
  - one for each subdetector: arich, cdc, ecl klm, pxd, svd, top, vxd
  - core packages: framework, reconstruction, tracking
  - data taking: daq, hlt, rawdata, trg
  - data quality: alignment, calibration, dqm, validation
  - data storage tables: mdst, skim
  - MC: decfiles, generators, geometry, simulation, structure
  - background: background, beast, ir
  - offline analysis: analysis, b2bii, mva
  - documentation / outreach: display, masterclass, online_book
- each package has one or two librarians (total number of librarians: 37)
- code written in C++
- one shared library created per package and installed in top-level lib directory
- build system based on SCons

Modular structure

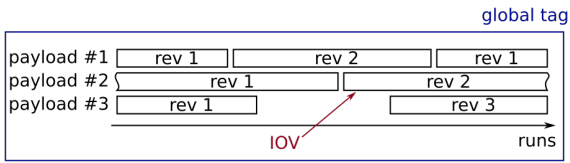
- linear arrangement of C++ modules in a path
- core functions of modules
  - initialize
  - beginRun
  - event
  - endRun
  - terminate
- python steering script to set up path





Conditions Database

- storage place of additional data needed to interpret and analyze the data that can change over time, *e.g.*, detector configuration or calibration constants
- payloads: binary objects (usually ROOT files) identified by name and revision number
- each payload has defined intervals of validity (iov), *i.e.*, experiment and run range
- globaltag: collection of payloads and iovs for a certain dataset, identified by unique name



- once prepared globaltag is immutable and cannot be modified any further to ensure reproducibility of analyses
- different processing iterations use different globaltags
- globaltag of reconstruction stored in metadata and automatically applied
- chain of globaltags possible

Data-taking

- basf2 runs on 12 high-level trigger nodes
- ZeroMQ
  - acts like concurrency framework while looking like an embeddable networking library
  - sockets that carry atomic messages across various transports like in-process, inter-process, TCP, and multicast
  - fast
  - asynchronous I/O model → scalable to multi-core operation

Reconstruction chain

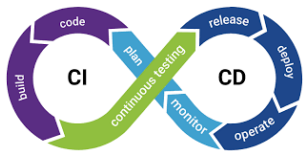
- RootInputModule
- geometry
- clustering of calorimeter
- clustering of pixel and silicon vertex detectors
- track finding
- track fitting
- track extrapolation
- track-cluster matching
- software trigger
- post-filter tracking
- PID
- RootOutputModule

Tracking

- pattern recognition / track finding
  - finding hits belonging to the same charged particle
  - SectorMaps → Segment Network → Cellular Automaton to find longest paths
  - inter-detector track finding via Combinatorial Kalman Filter
- track fit
  - extracting track parameters from fit to collection of hits
  - Deterministic Annealing Filter (DAF)
  - in Belle II currently use GenFit package (DOI:10.5281/zenodo.10301439)

Unit-tests

- first layer of software validation
- run full test suite for each commit of open merge requests and each merge into main or release branch
- currently about 1000 unit-tests of C++ code using GoogleTest
  - check basic functionality of modules, return values of functions and variables
- about 300 additional python tests
  - make sure that standard scripts do not crash
  - compare output of certain scripts with reference expectation, *e.g.* for mdst backward compatibility
- unit-tests intended to catch non-trivial dependencies and implications of code changes
- running all tests (in 16 parallel processes) takes 15 - 20 min



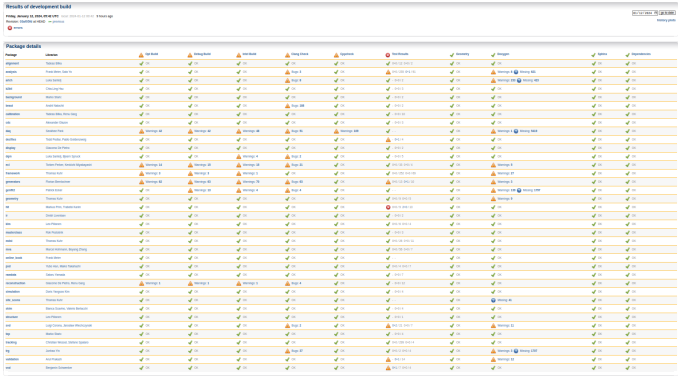
Nightly validation

- run once per day (night)
- workflow of nightly validation
  1. generate smallish samples
  2. run validation scripts
  3. create output histograms
  4. comparison with reference
     - calculate p value of histogram compatibility
     - calculate performance numbers, *e.g.*, width of distribution
- plots of various software releases uploaded to web server
- email notifications sent out to assigned contacts

Nightly validation

Monitoring

- nightly build run with different configurations (debug, intel, clang)
- many resource checks (memory consumption, execution time, output file size)
  - summarize build warnings, cppcheck, doxygen check, dependency check, geometry overlap check



- history plots of warning and error counters as well as resource usage

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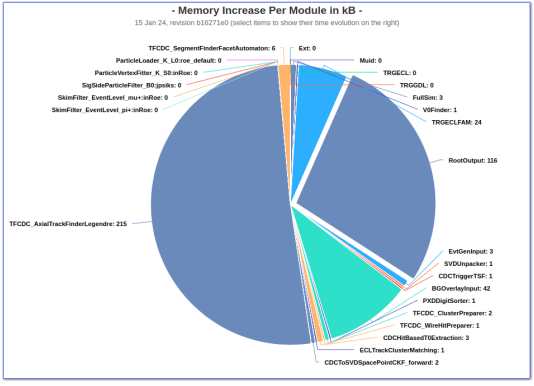

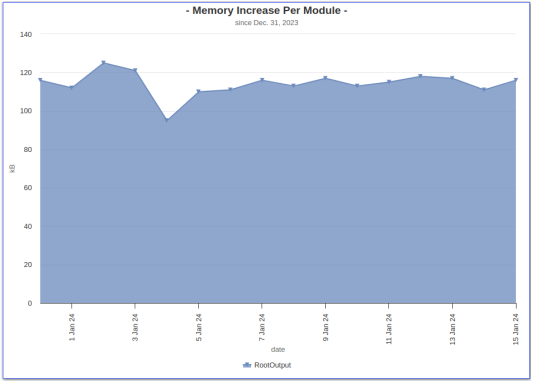

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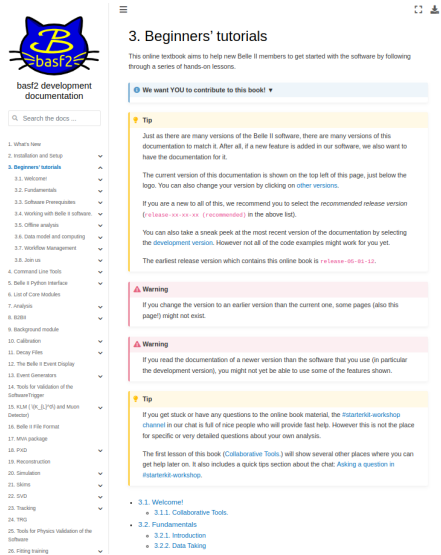
Documentation

- good documentation crucial to (recruiting) process of software development and maintenance
- sphinx
  - use reStructuredText
  - use sphinx's autodoc feature to conveniently create documentation based on python's docstrings
- doxygen for C++ documentation
- tests for (almost) all packages to ensure that everything is documented



Supported environments

- basf2 meant to work on any recent 64bit Linux system but only tested and binaries provided for
  - Enterprise Linux 7 or CentOS 7
  - Enterprise Linux 8 or CentOS 8
  - Enterprise Linux 9 or AlmaLinux 9
  - Ubuntu 20.04
  - Ubuntu 22.04
- basf2 distributed on cvmfs
- ARM version under development
- central Buildbot instance connected via gitlab webhooks to code changes → triggers builds on various workers

Release policy

- major releases
  - once a year
  - very thorough validation
  - contains all software changes that are merged to the main branch
- minor releases
  - frequency: one to two per major release
  - limited amount of new features, usually for specific purpose
- patch releases
  - mostly for bug fixes, especially for data-taking and calibration
  - during data-taking synchronized with maintenance days
- light releases
  - every two months
  - for introduction of new offline data analysis features
  - contain only framework, mdst, mva, analysis, skim, geometry, online_book, and b2bii packages
  - no unpacking or digitization $\Rightarrow$ only mdst and udst can be processed

Conclusion

- Belle II software publicly available (Comput Softw Big Sci 3, 1 (2019) and DOI:10.5281/zenodo.5574115)
- C++ code with python interface
- serial execution of dynamically loaded modules to process collection of events
- Conditions Database stores settings and calibration constants
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Thanks for your attention!