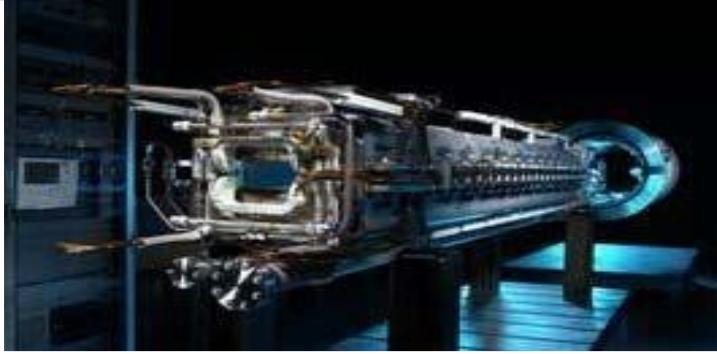
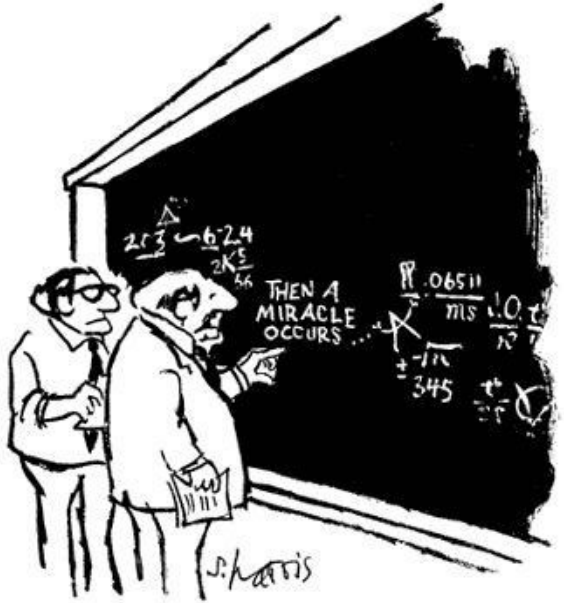


FAIR Accelerators:

Open-Source Challenges & Opportunities

Ralph J. Steinhagen
FAIR Commissioning & Control PL (PSP 2.14.17)

Research Data Management at GSI/FAIR Workshop
4-5 July 2022, GSI, Germany, https://indico.gsi.de/event/14680



"I think you should be more explicit here in step two."

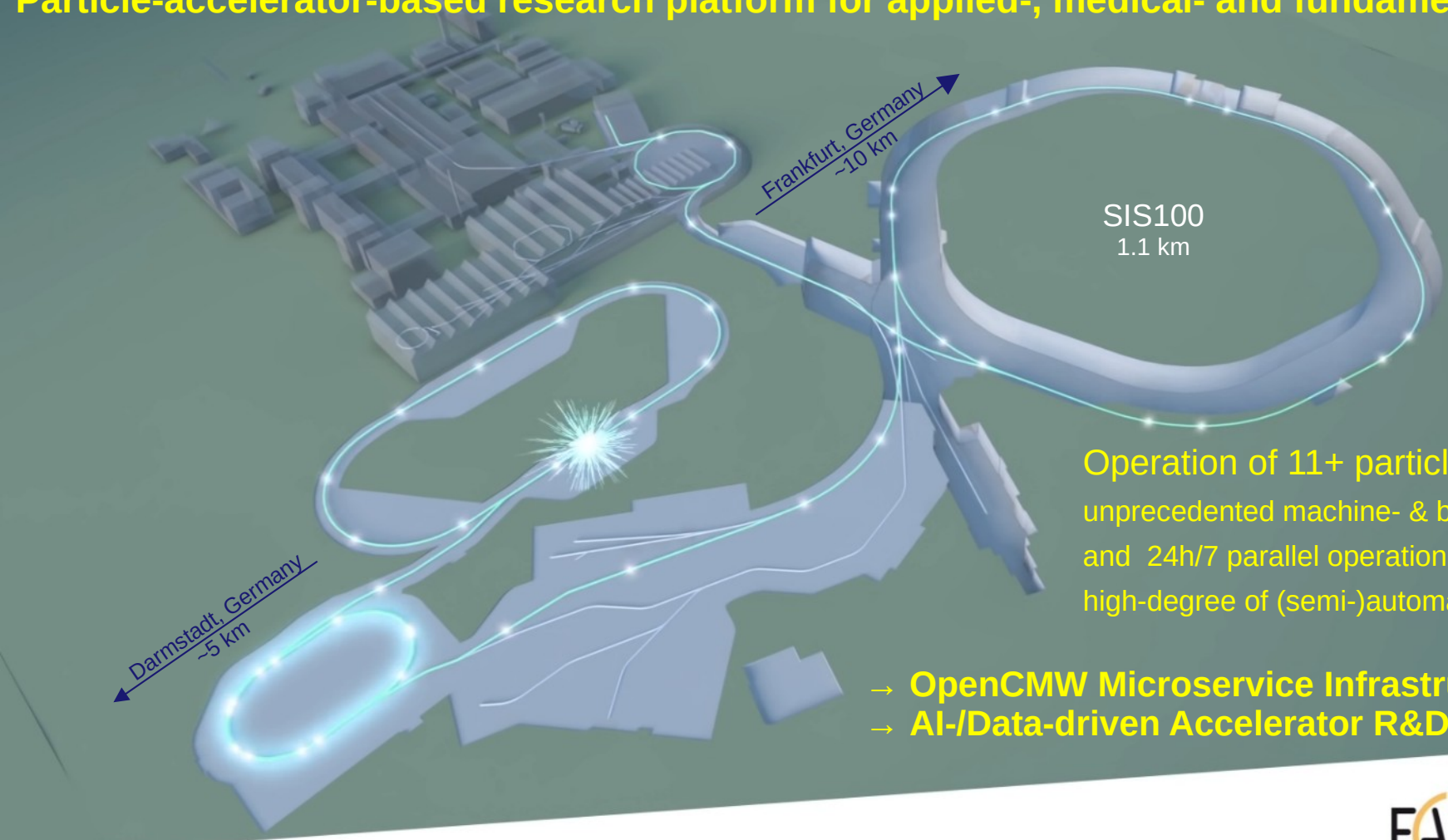
Finland France Germany India Poland Romania Russia Slovenia Sweden UK

GSI HELMHOLTZ ASSOCIATION FAIR

Facility for Anti-proton and Ion Research

"The universe in the laboratory"

Particle-accelerator-based research platform for applied-, medical- and fundamental sciences



Operation of 11+ particle accelerators:
unprecedented machine- & beam-parameters,
and 24h/7 parallel operation require
high-degree of (semi-)automation

→ **OpenCMW Microservice Infrastructure**
→ **AI-/Data-driven Accelerator R&D**

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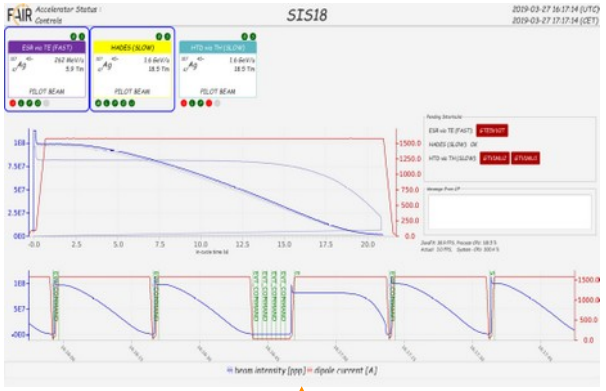
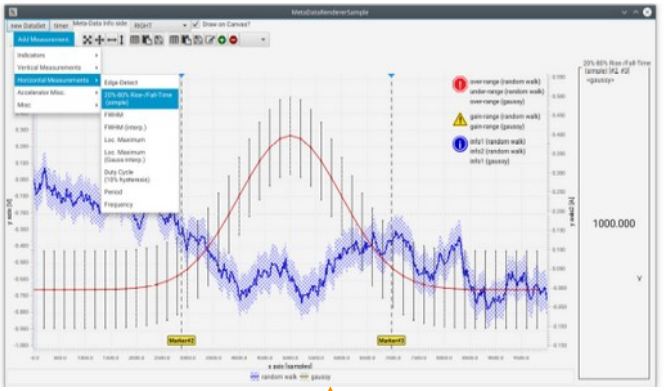
(Semi)-Automation of FAIR through Microservices

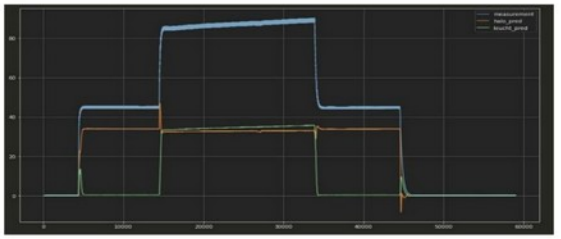
monitoring/web-type status applications



interactive control applications



AI-based
research applications



user-interfaces

micro-services

O(10 → 100 kS/s)

ZeroMQ+{REST}-based middleware

measurement systems

digitizer

x2k

sensor data

feedback controllers

$f(\langle input \rangle) \rightarrow \langle actuator \rangle$

(fairly sub-domain specific)

x15 x N_{acc}

corrections

device controller

DAC

x1k

setting supply

nano-sec. timing

low-level hardware

O(0.1 → 250 MS/s)

particle beam

moving at ~300000 km/s

Experiment

(energy, position, particle-type, -angle, -spot size, -spill-rate, bunch-length, ...)

O(0.001 → 2 GS/s)

>100k diagnostics sensors

>1000 magnets, RF cavities, ...

Accelerator Open-Source Core Activities

https://github.com/fair-acc

A: OpenCMW – Open Common Middle-Ware
library for accelerator equipment- and beam-based control systems at FAIR

- efficient, sustainable, and secure middle-ware minimising distributed micro-service architecture boiler-plate code
- an open reusable standard that facilitates contributions and collaborations with external partners

B: gr-digitizer – generic digitizer and SDR platform for FAIR
i.e. “high-bandwidth distributed oscilloscope & spectrum analysers with thousands of signals, distributed across the FAIR facility, and synchronised from ms- down to the ns-level”

- based on GNU Radio modular high-performance signal processing framework
- part of FAIR’s digitisation and FCC ‘Digital Control Room’ strategy

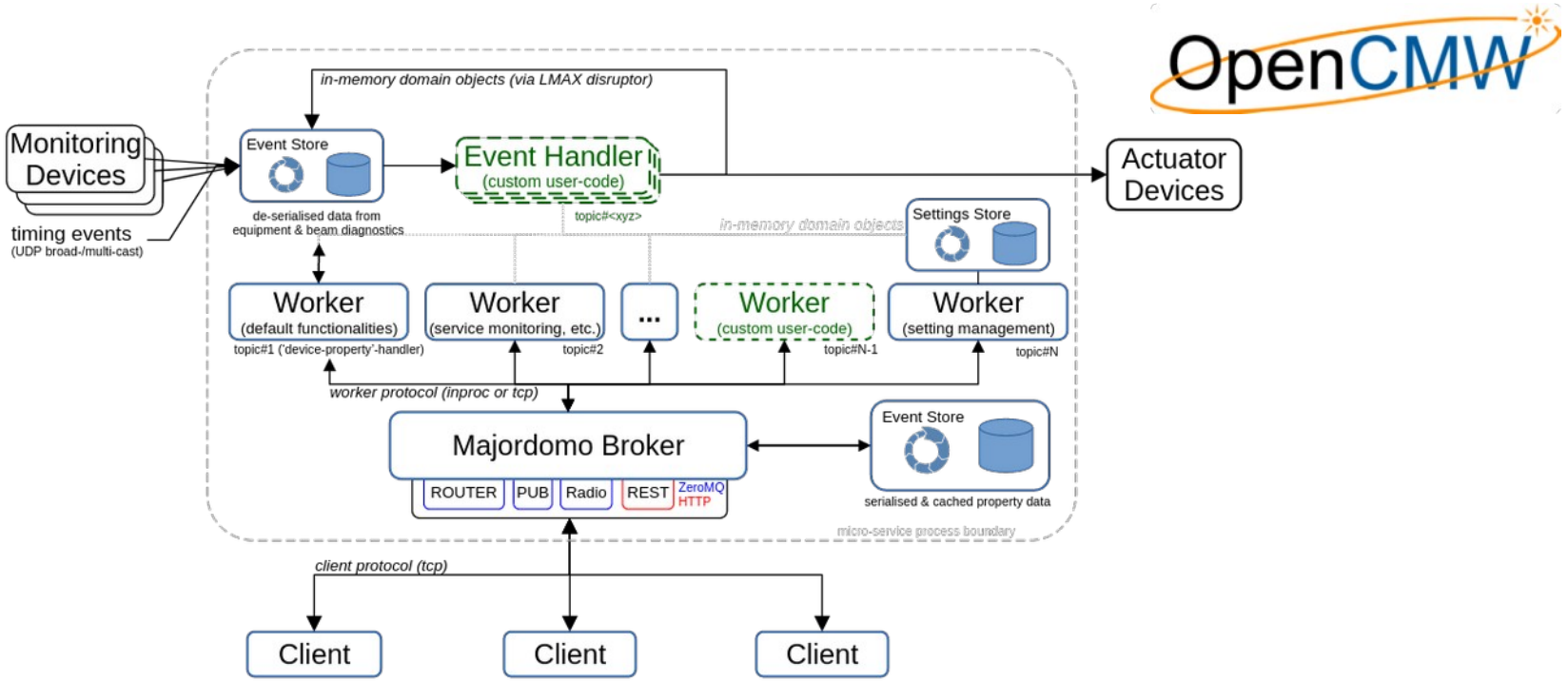
C: ChartFX
scientific charting library focused on performance optimised real-time data visualisation at 25 Hz update rates for datasets with a few 10 thousand up to 5 million data points.

- used in-house by a large number of control room UI application
- large user-community >300+ in non-physics academia and industry (robotics, bio-medical, finance, …)

... following slides briefly cover their scopes and why we opted for an open-source strategy

Open Common Middle-Ware – OpenCMW

https://github.com/fair-acc/opencmw-cpp



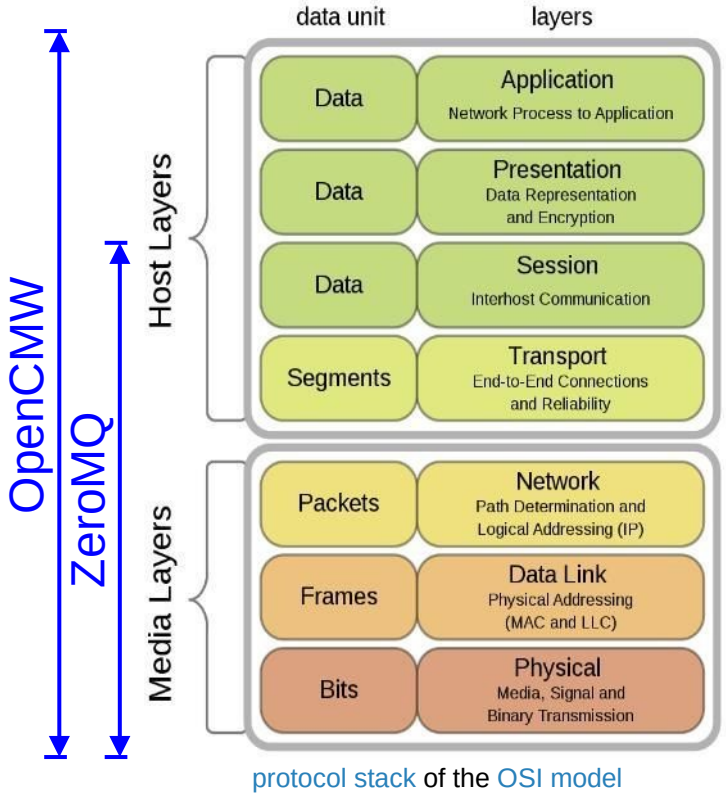
TL;DR summary:

- low-entry threshold for beginners with sufficient domain-expertise but limited C++ expertise
- open, extendable, auditable, and long-term maintainable by limited pool of C++ experts

Intros: https://indico.gsi.de/event/14294/#2-introduction-to-opencmw, https://indico.gsi.de/event/14978/

Open Common Middle-Ware – OpenCMW
Core: Majordomo Transport Protocol

… aims at an extendable full protocol stack implementation…



protocol stack of the OSI model

… with (optional) ‘batteries’ included:

- Transport protocols:
  - Majordomo (ZeroMQ: RFC 7/MDP & 18/MDP),
  - RDA3 (proprietary GSI/CERN transport
  - HTTP/REST (long-polling, SSE): web-services, routable to non-GSI/FAIR networks
  - RADIO/DISH (low-latency UDP) – WIP
  - *… <add your version here>*
- Serialisers
  - YaS (binary): annotated type- and physical unit-safe
  - CmwLight (binary): ACC-specific binary protocol
  - JSON (text): data exchange with web-based REST clients
  - YML (text): service config management (human readable)
  - HTML: server-side rendered fixed-displays (+WASM), expert diagnostics tools, ...
  - *… <add your version here>*
- RPC/Streaming call-backs: lambda → convenience classes
- lock-free circular buffers → event sourcing pattern
- thread-affinity, -tools & -pools
- settings management, ...

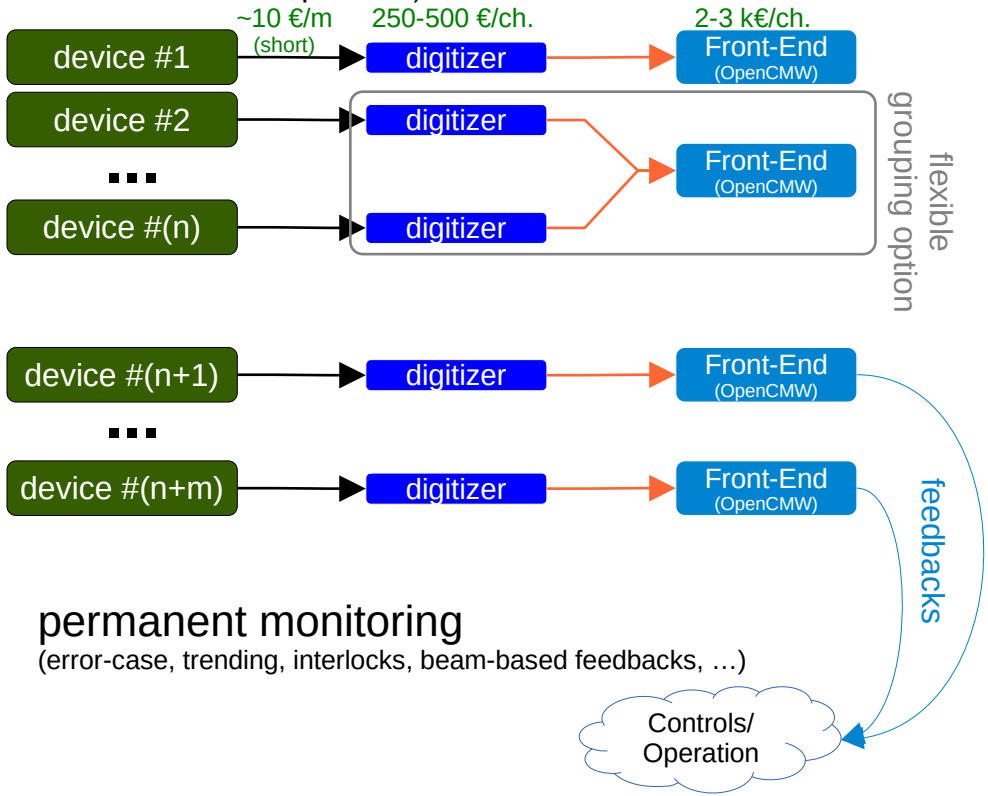
Digitization of Analog Signals at FAIR I/II

https://edms.cern.ch/document/1823376/

ranges: DC → 10 MHz, DC → 200 MHz, DC → 0.5 (1) GHz
courtesy M. Thieme, V. Kleip, K. Lueghausen (ACO)

\+ LimeSDR
0.1 MHz → 4 GHz

- new open-source concept
  (underlying assumption: scopes/digitizers are cheap, RF switches are expensive)

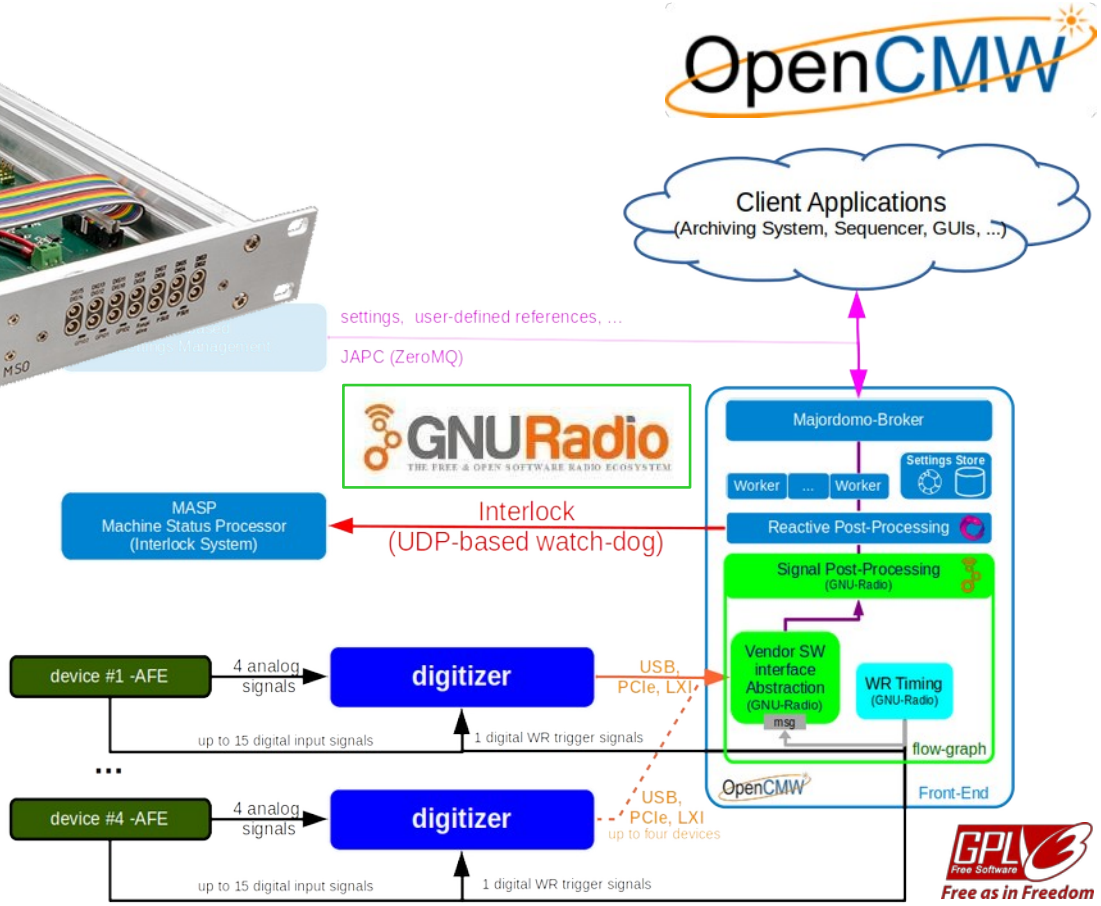


permanent monitoring
(error-case, trending, interlocks, beam-based feedbacks, …)

Open-Source SW & 19” Mechanical Integration

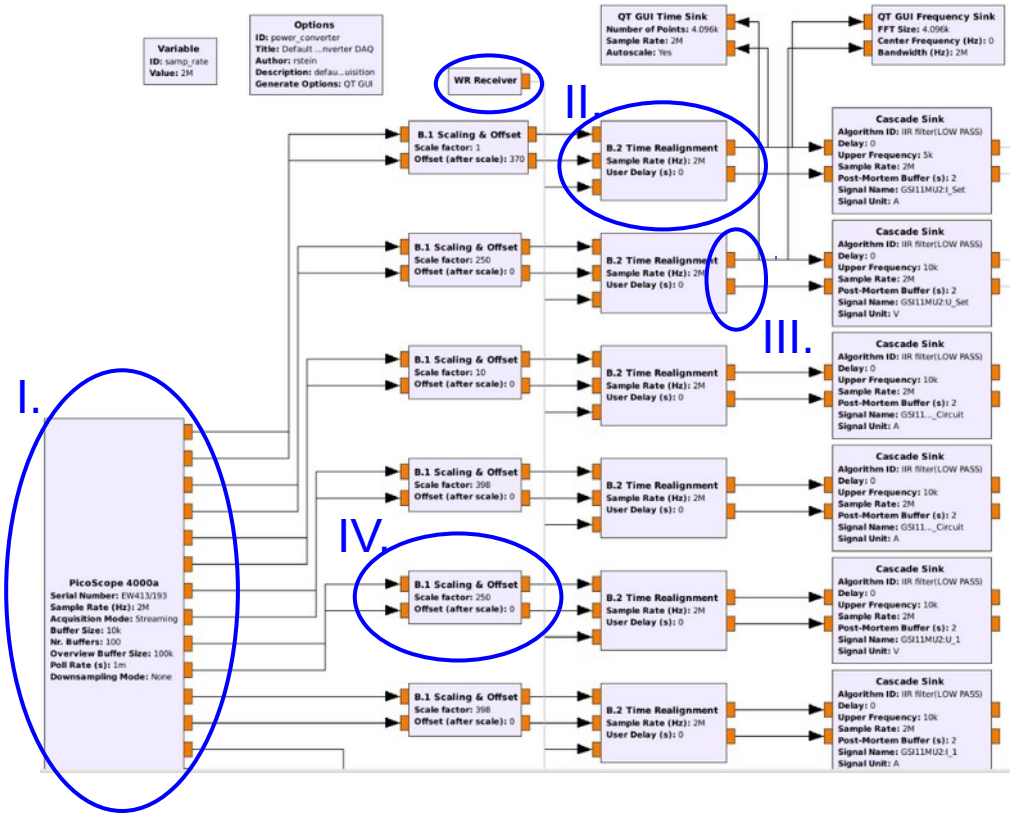
both are open reusable designs: GPLv3 & CERN OHL

open source hardware



presently deployed ~200 systems
→ 300+ systems @FAIR
(many different internal and external groups involved)

General Signal-Flow Scheme – simple example dipole circuit monitoring



Noteworthy things:

I. Integrated high-performance digitizer & SDRs

II. ns-level signal synchronisation across 300++ front-end controllers (FECs) via
(https://github.com/fair-acc/gr-digitizers)
   a) 'White-Rabbit' timing receiver
   b) GPS pps signals
   c) SW-trigger (i.e. UDP multicast)

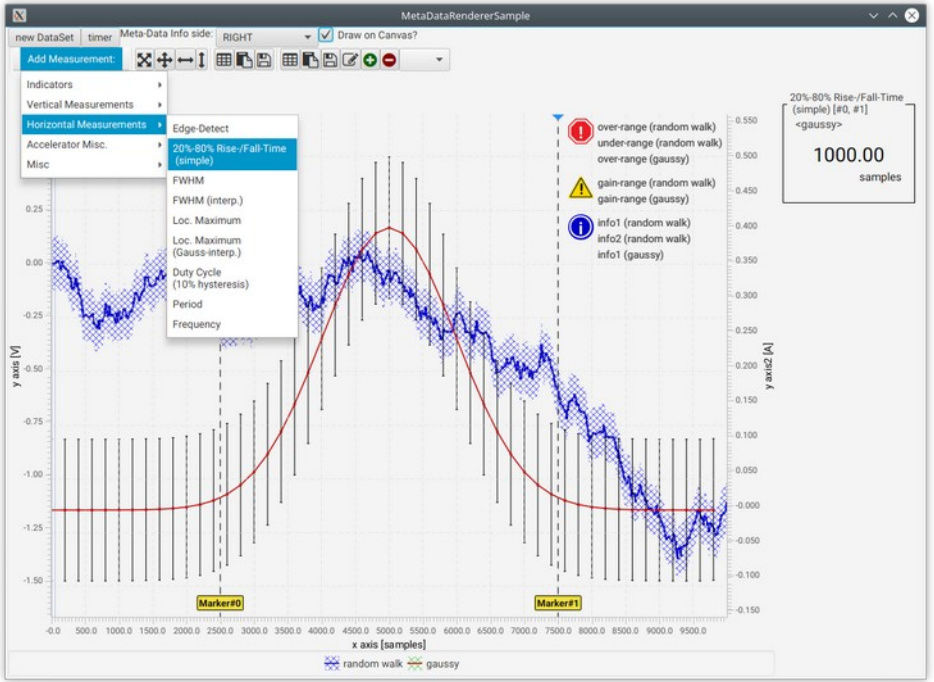
III. mean + stdev processing
   a) … scientific rigour
   b) … signal-integrity checks
   ↔ used in feed-back loops (automatic stop/fail-safe)

IV. run-time flow-graph modifications
(https://github.com/fair-acc/gr-flowgraph)
   a) block parameters
   (e.g. gains, timing-triggered threshold/interlock functions, χ^2-fits, conditional processing, …)
   b) online- & user-defined post-processing
   (~T&M equipment)

- modular open-source high-performance post-processing frame-work (SIMD, GPU-accelerated, ...)
  (large industrial & academic community/eco-system)
- "Best of both worlds":
  - extensible by non-SW experts (UI support, lab-setups)
  - specific/performance-optimised processing blocks written by SW-experts (C++ & Python)

ChartFx – Scientific Charting of Real-Time Beam & Accelerator Data

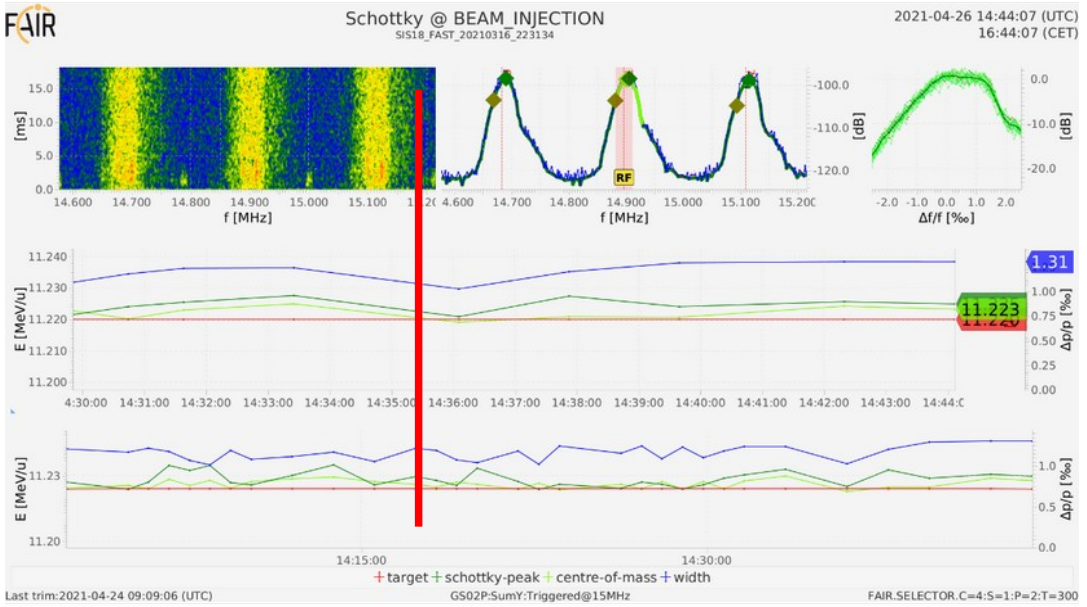
- original design:
  ”all ACC-UIs shall be Java-based”
  N.B. scientific computing/signal-processing remains a niche in Java
- no open-source/commercial charting library available at that time
  → co-use of CERN’s ‘JDataViewer’
  (proprietary use, closed-source → no rights to extend usage to external GSI/FAIR collaborators)
- in addition: became obsolete with Java’s ‘Swing→JavaFX’ transition
  technology effectively died out with most not wanting to publicly invest into this eco-system

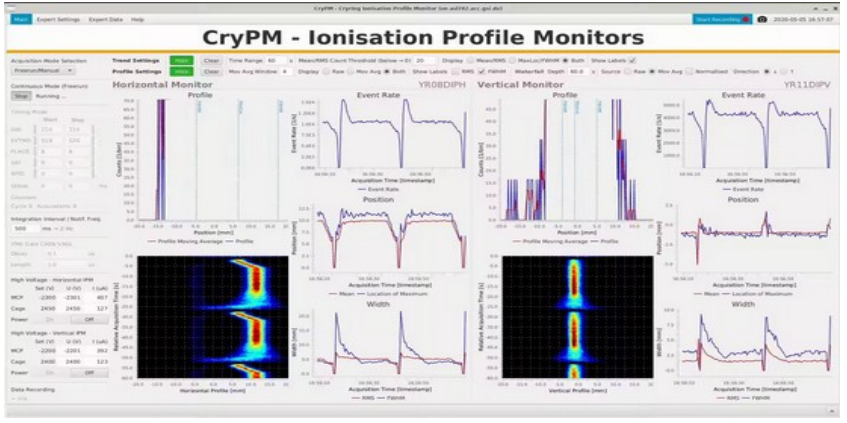


- needed to stick with Java, rolled-out own version using JavaFX → became ‘ChartFX’
- primary design goals:
  A) scientifically accurate and high-performance plotting of real-time data
  B) FLOSS from the beginning: open eco-system anyone can use, ...

ChartFx – Scientific Charting of Real-Time Beam & Accelerator Data

- ‘successful ↔ open-source’ project: versatile, performance, openness, ...
  - used in-house by a large number of control room UI application
  - large user-community >300+ in non-physics academia and industry (robotics, bio-medical, finance, …)
- attracted many 3rd party contributions: new features, review-comments, bug-fixes, ...





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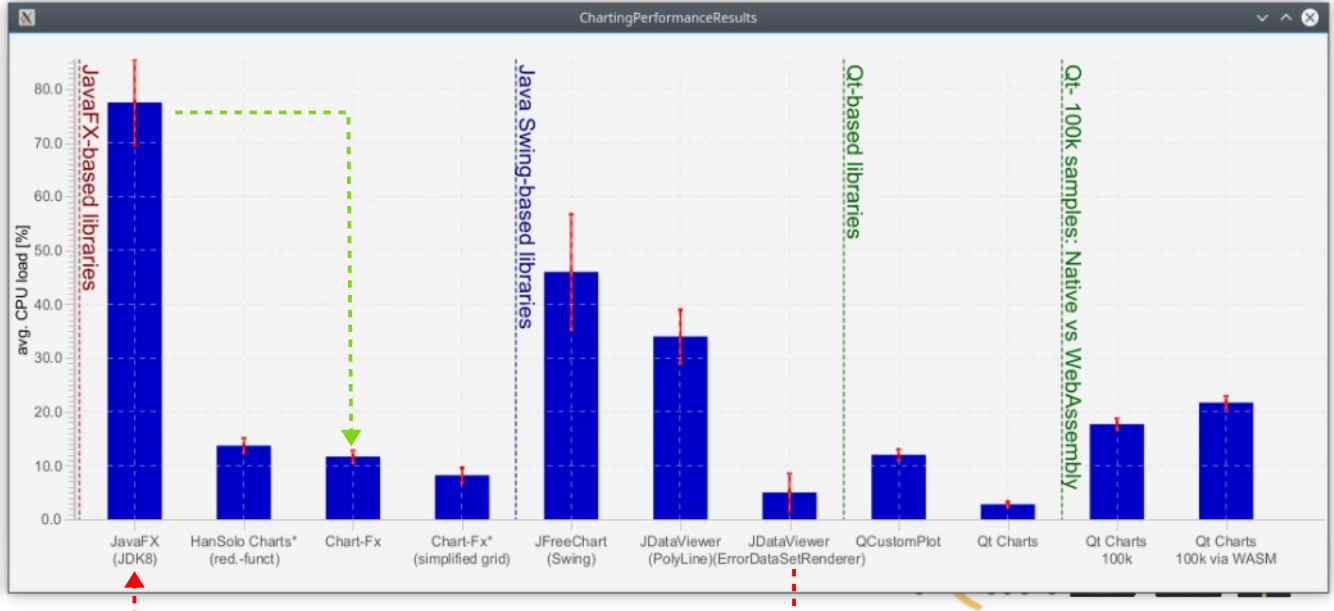

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- … prefer universal and produce stable underlying laws
- … requires reproducibility and 'FAIR' principles (**F**indability, **A**ccessibility, **I**nteroperability, and **R**euse):
  - replicate data analysis → Open-Access & Open-Data
  - replicate experimental setup and measurements
    → **Open-Source** since most of our analyses are SW-driven

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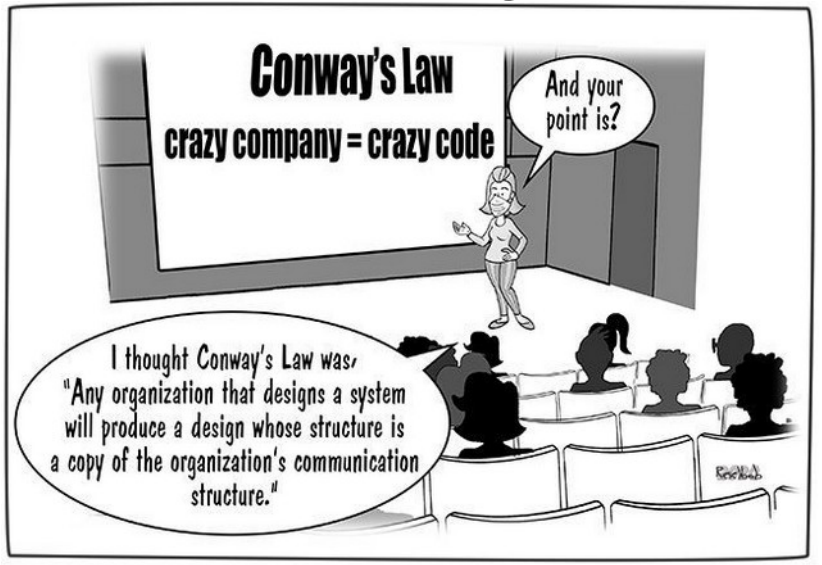
Why Free and Open-Source – The Organisational Challenge

- our (maybe yours?) developments tended to be ...
  - immediate need, functionality, and limited resources driven
  - closed-source and w/ limited ‘works-as-is’ documentation
  - available only for specific platforms, dedicated machines, and for a selective pool of specially trained developers



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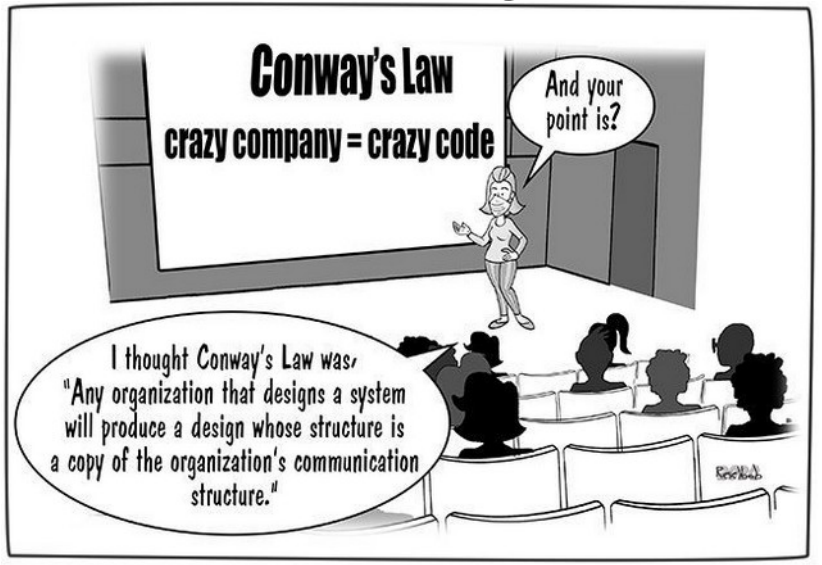

- fear of support & maintenance burden/risks lead to a slow creeping process that:
  - forced fixed long-term design choices
  - constrained continuous improvement and roll-out of new features
  - accumulated technical debt → bloated code and furthered high maintenance efforts
  - strong emphasise on control and minimising potential heterogeneity of expanding software eco-system rather than embracing an evolution of new ideas and concepts

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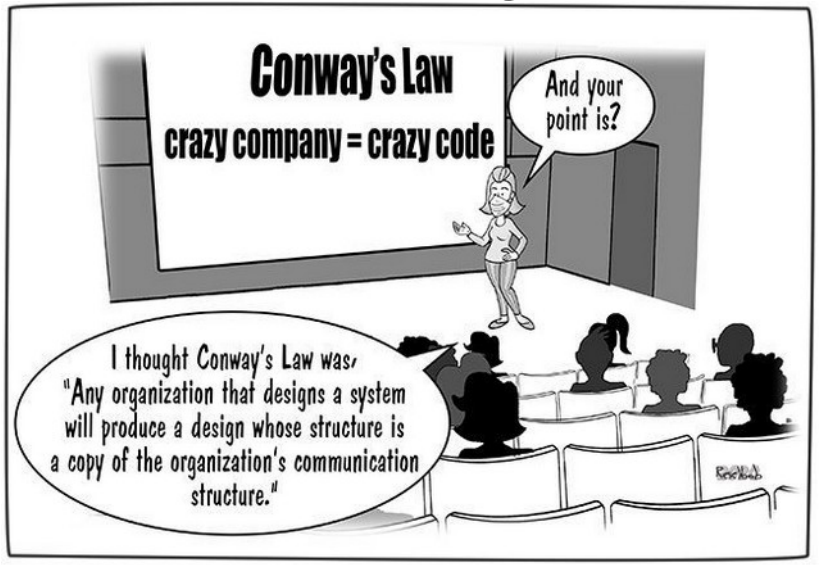

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- relied on formal specific collaboration agreements (effectively NDAs)
  → high threshold for including 3rd parties
  → difficult to contract generic developments to external companies/universities

Why Free and Open-Source – Benefits II/III

… intentionally aimed at breaking these old bad habits & to open-up for new concepts, i.e. 'Inverse Conway's Law': *"purpose-led adoption of agile, lean & clean development principles that are inviting for other scientists/engineers and shape the organisation"*

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2. enabled ad-hoc & required collaborations with ext. partners with low legal threshold
   - shared innovation – cross-pollination of ideas and designs
     - feedback from industry, best-practices, minimised risk for intellectual in-breeding
   - facilitates (in particular unexpected) 3rd party contributions (> 300 users)
     - positive feedback & external contributions outweigh our community support effort

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3. fosters higher quality assurance and coding standards
   - higher SW quality standards: peer review, feedback, bug reports/fixes, …
   - static code-analysis, CI/CD and other otherwise inaccessible tooling

Why Free and Open-Source – Benefits III/III

4. premise for sustainably growing community and software eco-system,

FAIR GSI

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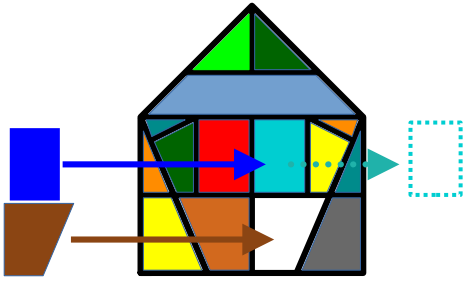
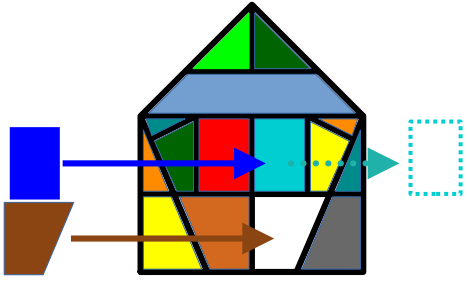


(prescriptive rigid) frameworks:
user implement stubs
limited options to exchange
or to extend
(often monolithic structures)

Why Free and Open-Source – Benefits III/III

4. premise for sustainably growing community and software eco-system,
   - democratises development → transparency w.r.t. internal/external goals and processes
     → being predictable & long-term dependable (i.e. 'playing with open cards' and creating a public track record)
   - keeping a low-entry threshold – being open for and value small contribution and changes
     - limit mandatory external technical dependencies
     - limit prior required knowledge to use for own development/research
     - better documented and open build processes → better auditable QA processes
       (e.g. controlled via public CI/CD-integrated agile development rules, styles and standards)
     - limit boiler-plate code → lean and 'clean code' principles
   - yields better design aiming at re-usability also in other domains
     (generic scalable vs. specific hard-to-extend/unmaintainable designs)
     - also: shared eco-system ↔ shared maintenance
   - core: 'prefer composition over inheritance'



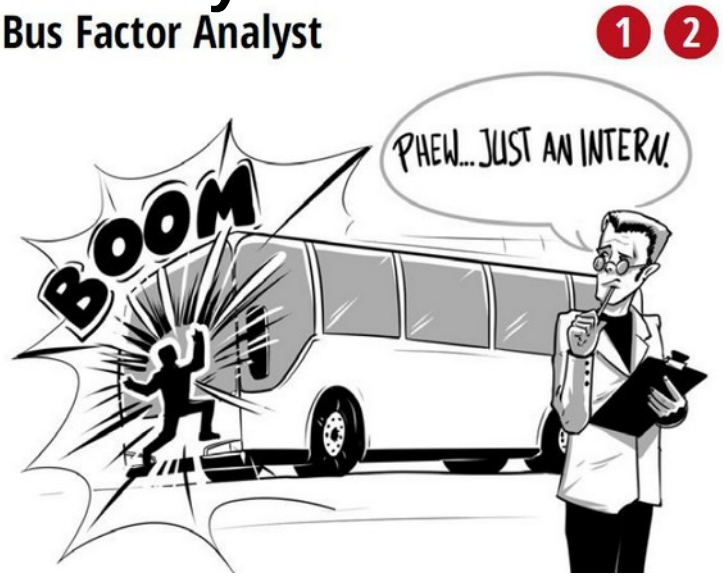
(prescriptive rigid) frameworks:
user implement stubs
limited options to exchange
or to extend
(often monolithic structures)

modular library:
user can opt-in what to use and
what is needed, free to extend,
modify, synthesise new ideas, …
(e.g. header-only libs)

→ fosters long-term maintainability, extendability, and real-world R&D impact FAIR GSI

A Better Impact of R&D – Bus Factor & Reusability

… *“number of team members that have to disappear from a project before the project stalls due to lack of knowledgeable or competent personnel"*, Wikipedia



https://www.playitstartup.com/

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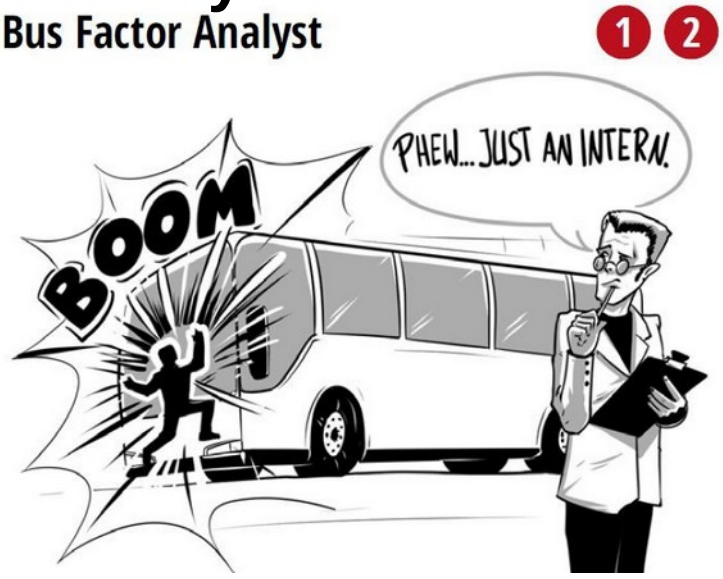

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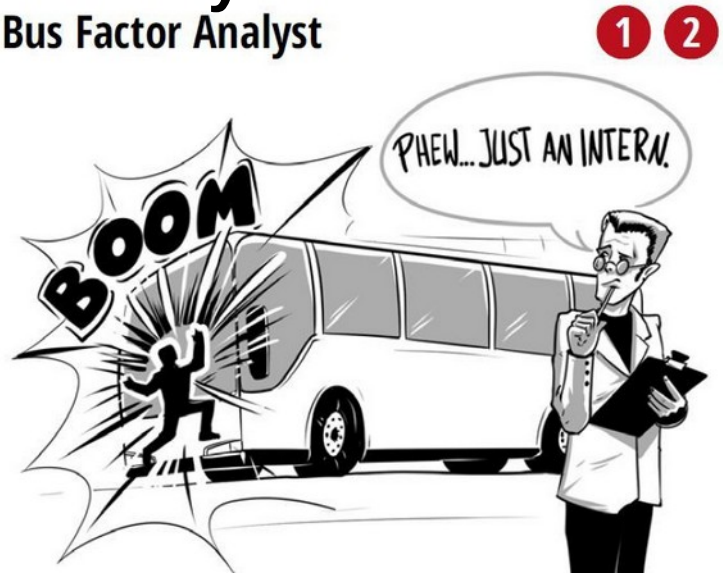
  → higher chance of being used, reproduced, and useful ROI



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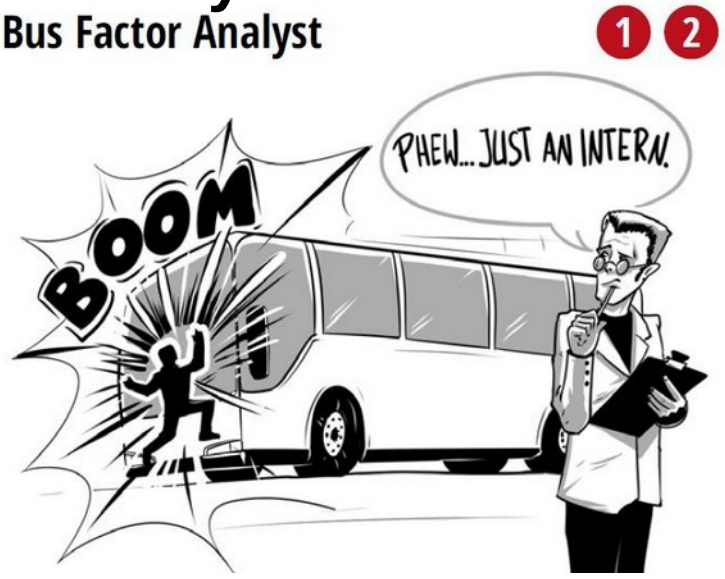

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… IMO a better metric measuring the real academic/societal impact of R&D projects

- fosters building communities and software eco-system
- cross-pollination of ideas from different domains → universality of R&D
- significantly improves code- and project quality → public show-and-tell
- more practical real-impact for both academics and society in general

Open-Source platforms (GitHub, GitLab, …) are strong-enabler/continuous tracker of improving the 'bus factor' and overall health/impact of an R&D project

FAIR GSI

Why Free and Open-Source – Our Responsibilities

- ‘free and open source software’ (FOSS) principle
  → essentially based on honesty, ethics, and common scientific citation practices
  - acknowledge previous work your work builds- and extends upon
  - ‘copyleft’: grant the same rights to others that you have received (i.e. pay-it-forward principle)

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- intrinsic democratic responsibility being publicly funded (no double taxation)
  → FSFE’s ‘Public Money Public Code’ campaign
  - min. ‘reinventing the wheel’ and wasting of public resources → ‘bus-factor’ metric
  - Have you seen/already signed this?
    (N..B. it’s also in-line with our government coalition policy)

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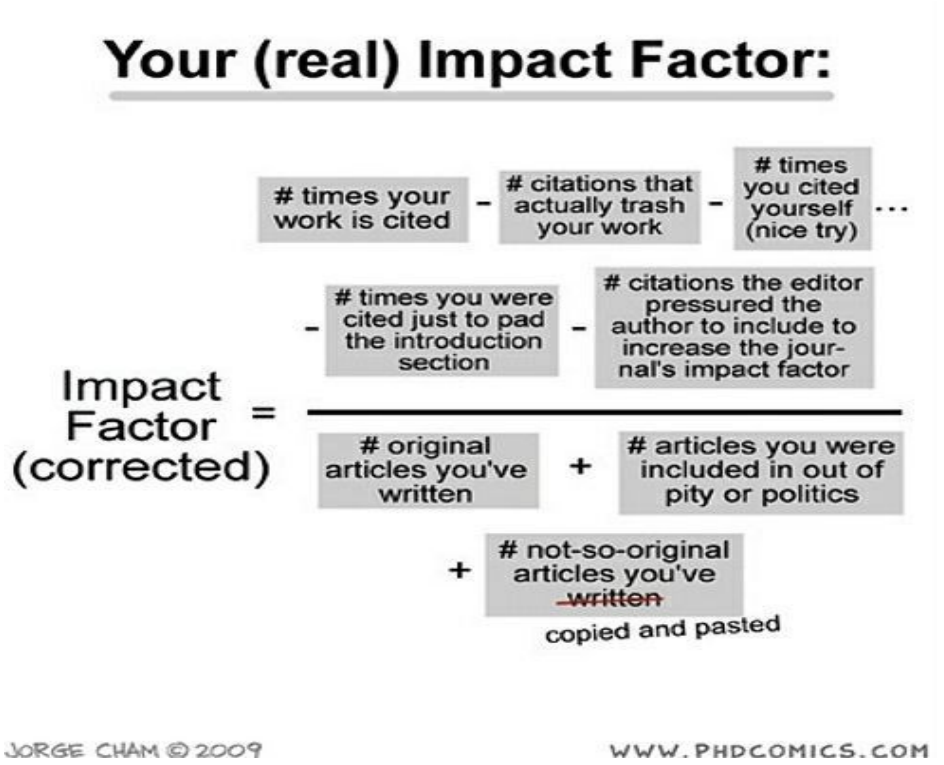
- More general open question:
  ”Should GSI/FAIR at large publicly commit to the ‘Public Money Public Code’ statement and adopt a policy where FOSS is the mandatory default* for R&D?”
  - *with exceptions to this being explicitly justified, cost-benefit analysed, and be peer-reviewed?

FAIR GSI

APPENDIX

Historical Measurements of R&D Impact – h-index et al.



We know that most of such simple metrics are wrong *… but often seem to not accept this*

- social media info war, R&D funding processes, 'reward function gaming' (especially in AI)
- broken peer-review processes, under-powered studies, ...
  e.g. John P. A. Ioannidis, "Why Most Published Research Findings Are False", PLOS Medicine, 2005, https://doi.org/10.1371/journal.pmed.0020124

Ockham's Razor

- *… There are always infinitely many potential explanations for any observation*

→ *Assume explanation with the least number of extra or unproven assumption*

William of Ockham
1288-1348

- More “modern” version:
  - “Rule I. We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.” (Isaac Newton, Principia mathematica, 1687)
  - “Whenever possible, substitute constructions out of known entities for inferences to unknown entities.” (Bertrand Russell, 1924)

- Without, no useful knowledge can be gained about anything, ever!

Bayes' Theorem

- Defines level of confidence P(H|E) in any Hypothesis, depending the level of support by the Evidence:

Thomas Bayes
1701-1761

$$P(H|E) = \frac{P(E|H)}{P(E)} \cdot P(H)$$

Posterior | Support | Prior

- shows what effect new evidence should have on our perception

"Extraordinary claims require extraordinary evidence."

Carl Sagan (paraphrasing Hume & Laplace)

N.B. alternate writing: $P_E(H) = P(H|E)$

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