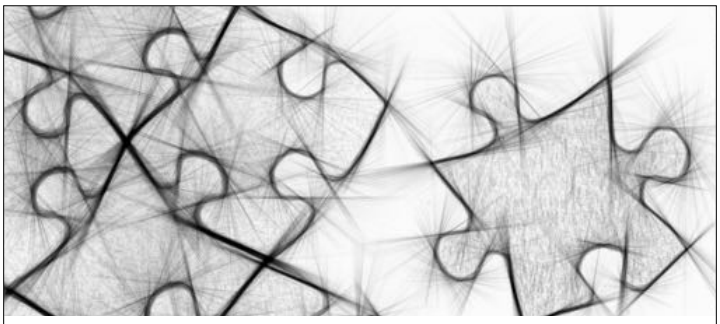


Towards Scalable Software Composition

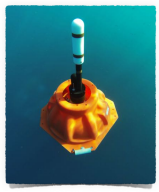
Sébastien Mosser
Research seminar, McMaster University
15/03/2021

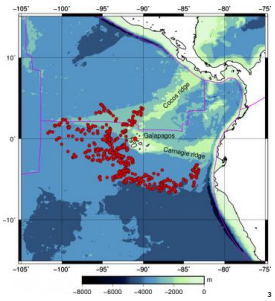
Sébastien Mosser

***Snowboarding** since 1995. **Composing** things since 2007.*

- 19-...: Associate Professor, UQAM
- 12-18: "Maître de Conférences", Univ. Côte d'Azur
- 11-12: Research Scientist, SINTEF
- 10-11: Postdoc, Inria Lille Nord-Europe
- 07-10: PhD student, Université de Nice

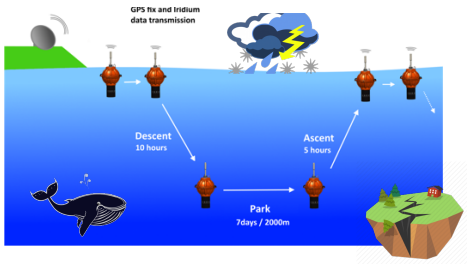
Example of Industrial Collaboration: MERMAID

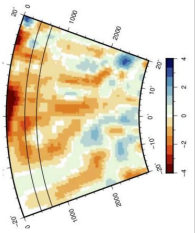




- Project **started in 2002** by Guust Nolet
- **Acoustic passive monitoring** of oceans
- Now **3rd generation** buoys deployed

Running Software, 20,000 leagues under the seas





Ok, but where is the composition?

Running Software, 20,000 leagues under the seas

"Can you build an AppStore for our MERMAIDs?"
- G. Nolet, 2016

- MERMAIDs are ***expensive***, and often ***idle***
  - *Oceans are full of challenges (80% unexplored)*
    - *Monitoring whales, plastic pollution, salinity, ..*
  - ***Compose** "data collection campaigns"*
- **A MERMAID is not a smartphone**
  - *Legacy ad hoc code (no operating system)*
  - *Hostile environment (salt, pressure), energy, ..*

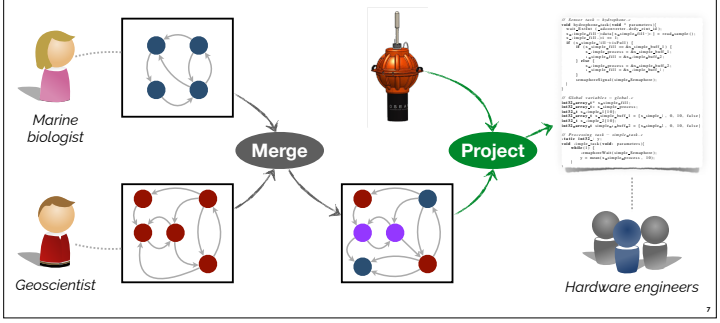
~~Running Software~~ Composing, 20,000 leagues under the seas

- ***So "composition" is all about hacking a buoy?***

- Scientific challenges:
  - **Conflict detection** among **requirements** expressed by **scientists**
    - **Static analysis** of the applications ***(what-if scenarios)***
  - **Modelling constraints** related to the "**hostile**" environment
    - **Empirical benchmark** and **simulation** for energy consumption

All these research challenges are related to composition!

Software Composition by example



Software Composition in the context of MERMAIDs

1. Model the MERMAID lifecycle & campaigns
   - ***Compose*** multiple campaigns together (*merge*, ≡)
   - ***Compose*** campaigns with the lifecycle (*project*)
   - **Open-source** domain-specific language for geoscientists (*MeLa*)
2. Simulate applications to validate the **composition**
   - **Benchmark** energy consumption
   - **Trade-off analysis:** ***Whales, Earthquakes, both?***

S. Bonnieux's PhD 2017-2020

[Sensors 2020] [Oceans 2019]

Funding: OSEAN-PACA + CNRS, ~140K$

Lessons learned: Software Composition matters! (2010-...)

- ***Divide*** to **conquer**, but ***compose*** to **vanquish**.
- Like *Mr Jourdain*, **you're composing without knowing it**:
  - ***Modularizing*** *code (e.g., packages, functions)*
  - ***Configuring*** *the Linux kernel*
  - ***Weaving*** *persistance into a Spring application*
  - ***Pulling*** *code from a Git repository*
  - ***Deploying*** & ***invoking*** *micro-services*
  - ...

Research challenge: Theoretical foundations + Trade-offs

(unsolved) Research Challenge

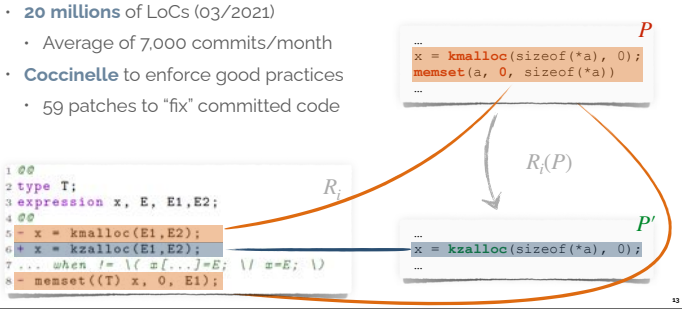
Can we make Software Composition Scalable?

Code rewriting at large-scale

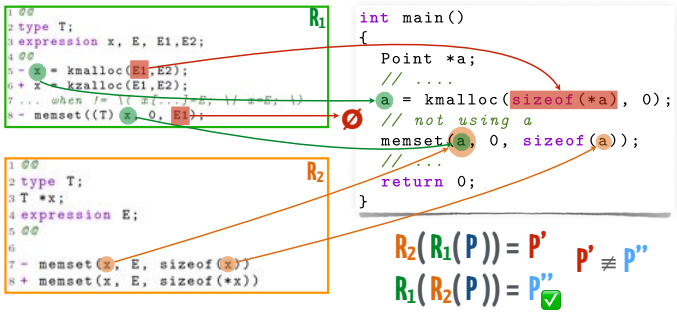
- Code rewriting **in a nutshell**:
  - $Rule : Program \rightarrow Program$
  - With ρ a rule and P a program, $P' = \rho(P)$ the rewritten one
- Code rewriting **from the trenches**:
  - **Image layering** for containers (Docker)
  - **Code quality** in the Linux Kernel (Coccinelle)
  - **Automated bug fix** in Android (Spoon)
- **Rules are composable** by definition:
  - $\rho_{12}(P) = (\rho_1 \bullet \rho_2)(P) = \rho_1(\rho_2(P))$

Rewriting the Linux Kernel

- **20 millions** of LoCs (03/2021)
  - Average of 7,000 commits/month
- **Coccinelle** to enforce good practices
  - 59 patches to "fix" committed code



Example of rule composition conflict



Scalability: Composing 59 rules!

- **How to identify conflicting rules?**
  - **Ordering** challenge
    - ***59!*** (10^{80}) ***combinations*** *to handle*
  - **Performance** challenge
    - *Patches are* ***time consuming*** *(~190 minutes)*
  - **Maintenance/safety** challenge
    - *How to* ***reduce the search space****?*
  - **Engineering** challenge
    - *Linux and Coccinelle are* ***non-negotiable***

https://github.com/torvalds/linux/tree/master/scripts/coccinelle

Abstracting rules composition

- Looking for **fixed points** at this scale is "***out of the question***"
- **Trade-off**: Let $\rho = (\varphi, \chi) \in (\Phi \times X) = P$, where
  - $\varphi : Program \rightarrow Program$ is an idempotent rewriting function
  - $\chi : Program \times Program \rightarrow \mathbb{B}$ is a postcondition checker ✅
  - **Assumption**: we can manipulate programs
  - $\ominus : Program \times Program \rightarrow \Delta$ (e.g., the `diff` command)
  - $\oplus : Program \times \Delta \rightarrow Program$ (e.g., the `patch` command)
  - $\odot : \Delta \times \Delta \rightarrow \Delta$ (e.g., a patch concatenation algorithm)

Modelling rules composition operators

- **Extending** the state-of-practice with **isolated composition**
  - Let p a program, $(\varphi_1, \varphi_2) \in \Phi^2$ two rewriting functions
    - $p_1 = \varphi_1(p), \Delta_1 = p_1 \ominus p,$ and $p_2 = \varphi_2(p), \Delta_2 = p_2 \ominus p$
    - $p' = p \oplus (\Delta_1 \odot \Delta_2)$
- **Generalizing** & Including **postconditions verification**

$$iso : Program \times P^n \rightarrow Program$$
$$p, \{\rho_1, \ldots, \rho_n\} \mapsto p_{iso} = p \oplus (\odot_{i=1}^{n} (\varphi_i(p) \ominus p)), \quad \wedge_{i=1}^{n} \chi_i(p, p_{iso})$$

B. Benni's PhD 2016-2019

[JSEP 2019]

Empirical validation

- **Dataset** considered for evaluation:
  - **Linux**: Randomly sampled **19 versions** (1/month)
  - **Coccinelle**: rules triggered when running "`make coccicheck`" (35)
- **Results**:
  - **Ordering**: Discovered **2 conflicting rules**
  - **Performance**: **Quicker** than sequential
  - **Maintenance**: ***2!*** instead of ***35!*** (10^{40}) to check
  - **Engineering**: **iso-functional** tooling

2 conflicts, 36% cases

Commit.id	Rewriter #1	Rewriter #2
38651683aa98	alloc_cast	memdup
4efe37f4c4ef	alloc_cast	memdup
b134bd90286d	alloc_cast	memdup
25a3ba610609	alloc_cast	memdup
bce1a65172d1	alloc_cast	memdup
2551a53053de	alloc_cast	memdup
bfd40eaff5ab	alloc_cast	memdup

https://github.com/torvalds/linux/blob/master/Documentation/dev-tools/coccinelle.rst

Can we leverage this composition model ? (Horizontal scalability)

- **Challenge** the abstraction to other **application domains**
  - ***Energy-efficiency*** *for smartphone applications*
  - ***Container-based deployment*** *of service architectures*

android

- **Scalability** dimensions: **Reuse & Ensure**
  - **Empirical** validation (22 android app, 11k images)
  - **Android**: identify ***overlapping fixes***
  - **Docker**: detect ***faulty containers*** *(ignored elsewhere)*

docker

[JSEP 2019] [ICSR 2018] [Amadeus Industrial GlobalTech Keynote 2018]

Lessons learned: Scalability matters (2018-2020)

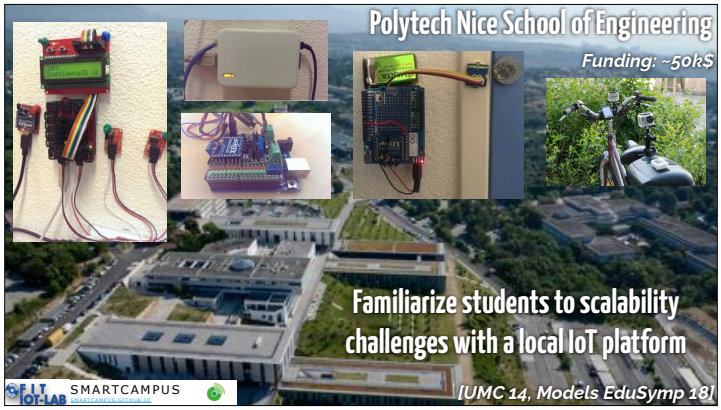
- Software engineering is **all about trade-offs**
  - From **optimal** to **usable** **(but trade-offs ≠ hacking/mundane)**
  - **Scalability as an afterthought is a mistake**

[JOT 2020]
[JSEP 2019]
[ICSR 2018]
[SAC 2018]

- **Research** on **composition models**:
  - Need to address **scalability issues**, at ≠ **dimensions**
    - *e.g., performance, maintenance, quality assurance, and reusability*
  - Will make the paradigm **usable at large-scale**
  - Requires **theoretical foundations** & **engineering** skill

Invited lecturer ENS Lyon (2018, 2019)

Funding*: NSERC Discovery (145k$),* CNRS (~20k$), UCA (~150k$)



Scalability: Formal properties do matter!

- **Challenge**: focus on **usage by developers**
  - *How to **develop** operators **faster** and **safer**?*
  - *How to **improve support** for operator's users?*

- **Modelling properties** associated to operators
  - ***Equivalent elements:*** *idempotency*
  - ***Operator folding:*** *associativity*
  - ***Avoid useless calls:*** *regularity, identity and absorption*
  - ***Order independence:*** *commutativity*
  - ***Composing composition operators:*** *distributivity*

ace

No silver-bullet!

Funding*: NSERC Discovery (145k$), 2020-2025*

Application domain: Source code management

Inria

- Team effort to **bind together Compilers & Software Engineering**
  - "***Équipe associée***" (start: 50k$) with ENS Lyon & Inria

UNIVERSITÉ DE LYON

- Explore **two dimensions of composition:**
  - **Charting** a large-scale **compiler infrastructure** (LLVM, ~10MLoC, Clang)
  - **Improving source code merging** at the abstract level (56M+ GitHub users)

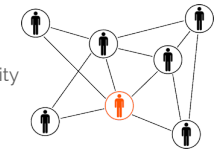
- **Skills**: *graph theory (Reinharz), compilers (Gonnord, Privat), and soft. eng. (Mosser)*

Ambition: Make `git-merge` & LLVM great again!

Application domain: Micro-services architectures

- **Micro-services** are a *de facto* **architectural style** in 2021
  - ***Starting a show on Netflix composes up to 700 services***

- Composition-related challenges: **No silver-bullet, no afterthoughts**
  - **Agile requirements** composition for **traceability**
    - *Natural Language Processing (Meurs), Certification (Polacsek, Blay)*
  - **Large-scale** deployment & **configuration** variability
    - *Polyglot development & Software product lines (Klewerton, Kruger) [ICSOC, SPLC2020]*



Ambition: Composition in heterogenous systems of systems!

1 Diving into Software Composition

Composing Rewriting Rules 2 *(2018-2020)*

3 Modelling & Scaling Composition *(2020-...)*

Conclusions & Take-aways 4

Software Composition is everywhere!

- Research driven by **industrial & practical collaborations**
  - **Geosciences** *(OSEAN-PACA+CNRS, ~140k$)*
  - **Embedded pipelines** *(Visteon, ~115k$)*
  - **Cyber-physical systems** *(Datathings technological transfer, ~225k$)*
  - Software **deployment** *(UCA, ~150k$)* & **visualization** *(UNS, ~150k$)*

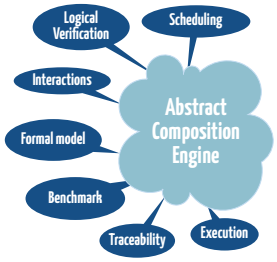
- **Research challenges (2020-...)**
  - ***Scalable*** composition models are **hard to elaborate**
  - ***Formal*** properties **impact software developers** daily life

Fundamentals of Composition Scalability

- Stop **reinventing a squared wheel!**

- **Abstract** the composition **expertise**
  - *Formal definition & tooling*
  - *Conflicts & Interactions handling*
  - *Verification & proofs*
  - *...*

- **Customize** for each **domain**



Time to consider (scalable) composition as a first class citizen

Recent composition results (2014-2020)

- **Technological transfer**
  - ***Visteon***: Pipeline composition *[ICSE 2019, SAC' 2018]*
  - ***DataThing***: time series composition (x 20) *[FGS 2019, SAC 2018]*
  - ***PulseTotem***†: Spin-off startup company *[SEAA 2014]*

- **Open-source software**
  - Incremental **exploration of software** *[SPLC 2020, ICSOC 2020]*
  - **Abstract Composition Engine** *[JOT 2020]*
  - **SmartCampus reference architecture** *[UMC 2014]*

https://ace-design.github.io/

Joining McMaster's Department of Computing and Software

- Faculty of **Engineering**
  - Strong **industrial ecosystem, multidisciplinary collaborations**
  - **Renowned** CS and SE **programs**
- Departmental **expertise**
  - **Digital & Smart Systems** research cluster
  - **Software Quality** (& theory of computation) areas of specialization
    - *E.g., "safety" of composed systems (emergent behaviours)*
  - **Teaching**: Software engineering
- **Hamilton**, Ontario
  - *Campus! Waterfalls! Great Lakes! Biking! Hiking! Canoeing!*

This work is a team effort


Jinx


Dumpling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