CRAM: C++ to Rust Assisted Migration

High-Confidence Software and Systems

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May 9, 2023

This material is based upon work supported by the Defense Advanced Research Projects Agency (DARPA) under Contract No. HR001123C0079. The views, opinions, and/or findings expressed in this document are those of the author and should not be interpreted as representing the official views or policies of the Department of Defense or the U.S. Government.

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The Story

C++: perhaps *the* language for efficient systems programming

- Inherits (from C) low-level memory manipulation capabilities
- Can cause memory-related crashes and vulnerabilities

Safer efficient languages do exist today: Rust!

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Intermezzo: Rust as the Language of Choice?

- **memory safety:** access via strict interface: *ownership*
- **efficiency:** no need for garbage collection (cmp. C#, Go, Java)
- **coolness factor:** modern language, supportive build system, active community

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The Story (continued)

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Safer efficient languages do exist today: Rust!

But what about legacy code??

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Lifting Legacy Code to Safer Languages (LiLaC-SL)

Goal: semi-automatic migration of legacy C/C++ code

Target: (your favorite) *safe* programming language

May: assume well-designed C/C++ code

Must: take advantage of target's idiomatic features

Must: deliver assurance of correctness and safety

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Safer efficient languages do exist today: Rust!

But what about legacy code??

CRAM: semi-automated migration from C++ to Rust

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Overview of CRAM

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Vision: From C++ to Rust

> *"Rust is like C++, except the [language semantics] forces programmers to do what they should be doing anyway."*
>
> -- Peter Aldous, GT

Implementing this vision:

Stage 1: *Refactor* the C++ program, to make it "Rust compliant":

- enforce ownership rules
- reduce mutability

Stage 2: Migrate the "safer" C++ to Rust, by lifting language idioms

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Technical Approach

"Migrating C++ to Rust from the inside out:"

Legacy C++

- ✓ efficient
- ⚠ potentially unsafe (crashes, exploits)

Refactoring →

Refactored C++

- ✓ efficient
- ✓ safer, hardened
- ⚠ still unsafe for future development

Migration →

Generated Rust

- ✓ efficient
- ✓ provably safe
- ✓ idiomatic, human-maintainable
- ✓ "modern"

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Does the 2-Stage approach work wonders?

Nah, cross-language migration is hard even for “similar” languages.

→ assume source *is well-designed*:

- ~~pointer-implemented data structures~~ (use STL)
- ~~low-level pointer manipulation, p-arithmetic~~
- ~~abuse of overloading, obscure code~~ (e.g., `operator=`)

→ afford partial user assistance

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CRAM-Style Refactoring and Migration

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Stage-1 Example: `Const` Hardening

C++: variables are by default *mutable* (assignable).

Rust: `let mut d: f64 = 0.0`

In C++, declare vars as `const` whenever possible:

- ✓ prevents some programming errors
- ✓ facilitates aliasing

Refactoring

```
      double segdist = p1->Distance(*p2);
```

```
const double segdist = p1->Distance(*p2);
```

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Stage-1 Example: Breaking Up Alias Nests

Refactoring multiple non-const references to same memory cell:

```
void multiple_borrows() {

  Point p;
  Point* p0 = &p;
  Point& p1 = *p0;

  f(p1);
  g(p);
}
```

```
void single_borrow() {

  Point p;
  Point* p0 = &p;
  // Point& p1 = *p0;

  f(*p0);
  g(*p0);
}
```

General principle: "safer in C++, ***required*** in Rust."

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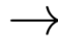
Stage 2: Rust Code Generation

Vision: after refactoring, migration mostly involves porting idiomatic language constructs:

```
switch (v) {
  case a:   <code_a>; break;
  case b:   <code_b>; break;
  default: <code_cde>; }
```



```
match v {
      a => { <code_a>   },
      b => { <code_b>   },
      _ => { <code_cde> } }
```

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Stage-2 Example: Container Traversal

```
for (std::vector<Point>::iterator
        p1 = pts.begin(), p2 = std::next(pts.begin());
        p2 != pts.end(); ++p1, ++p2)       { ... }
```

What defines a *container traversal idiom*?

1. **direction:** left-to-right vs. right-to-left traversal
2. **mutation:** destructive or non-destructive
3. **indexing:** 1, 2, 3 iterators

finite abstract "idiom space"

CRAM:
1. *abstract* traversal to idiom level, using static analysis + user
2. *retarget* to idiomatic Rust (using Rust idiom library)
3. *complete* construct by recursively calling CRAM on loop body

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Current Results

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Overview

Project duration so far: ≈ 12 months

Experimental use case: Valhalla routing library[1]

1. Valhalla coverage: ≈33% (growing)
2. Degree of automation: high
   → user assistance for disambiguation (multiple-choice)
3. Performance: (see next)
4. Code usability: very readable and idiomatic Rust (see next)
   → thanks to idiom library

[1] https://github.com/valhalla/valhalla

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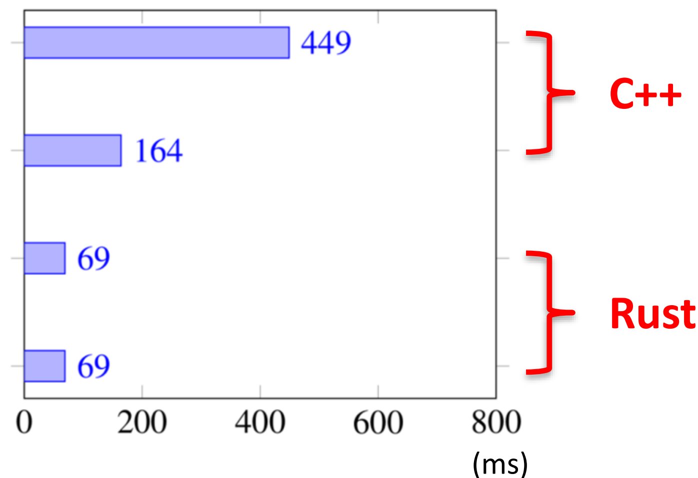
Performance

Example: runtime comparisons for a traversal of a (large) `list<Point>`:

- original
- after hardening refactorings
- after translation to Rust by an expert
- after translation to Rust using CRAM (resulting in rather different code)



Disclaimer: Evidence anecdotal at this time!

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Code Usability

```cpp
std::list<Point> trim_front(std::list<Point>& pts, float dist) {
  if (pts.size() < 2)
    return {};

  std::list<Point> result;
  result.push_back(pts.front());
  double d = 0.0f;
  for (auto p1 = pts.begin(), p2 = std::next(pts.begin()); p2 != pts.end(); ++p1, ++p2) {
    Point& next_point = *p2;
    double segdist = p1->Distance(next_point);
    if ((d + segdist) > dist) {
      double frac = (dist - d) / segdist;
      auto midpoint = p1->PointAlongSegment(next_point, frac);
      result.push_back(midpoint);

      pts.erase(pts.begin(), p1);
      pts.front() = midpoint;
      return result;
    } else {
      d += segdist;
      result.push_back(*p2);
    }
  }

  pts.clear();
  return result;
}
```

C++

Rust

```rust
fn trim_front(pts: &mut Vec<Point>, dist: f32) -> Vec<Point> {
    if pts.len() < 2 {
        return vec![];
    };
    let mut result: Vec<Point> = Vec::new();
    result.push(pts[0].clone());
    let mut d: f64 = 0.0f32 as f64;
    for i in 0..(pts.len() - 1) {
        let next_point: &Point = &pts[i + 1];
        let segdist: f64 = pts[i].distance(&next_point);
        if (d + segdist) > (dist as f64) {
            let frac: f64 = ((dist as f64) - d) / segdist;
            let midpoint: Point = pts[i].point_along_segment(&next_point, frac);
            result.push(midpoint.clone());
            pts.drain(0..i);
            pts[0] = midpoint;
            return result;
        } else {
            d += segdist;
            result.push(pts[i + 1].clone());
        };
    }
    pts.clear();
    result
}
```


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Outlook & Wrapping Up

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Outlook

Future will bring *deep-dives* into advanced C++ idioms:

- C preprocessor: `#include`s, cond'l compilation
- OOP: inheritance, exception handling
- Concurrency: portable threads (`std::thread`, not `pthread`)
- C++11 and beyond: smart pointers, concepts and modules
- General: Advanced Assurance Techniques

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CRAM: Capabilities & Benefits

Capabilities:

- ingest well-designed C++
- eliminate hazardous coding patterns in C++
- generate idiomatic, efficient (so far), and human-maintainable Rust code

Benefits:

- remove crashes and vulnerabilities due to common memory access errors
- improve development experience (via the Rust build system)
- modernize your code

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How to Obtain & Usage

Distribution:

- website with demo video: https://cpp-rust-assisted-migration.gitlab.io
- fully open-source: https://gitlab.com/cpp-rust-assisted-migration/code
- easiest to obtain via docker image
- dependencies: VS Code, Mnemosyne (both freely available)

Sponsorship:

- DARPA program: LiLaC-SL (Lifting Legacy Code to Safer Languages)
- Program Manager: Dr. Sergey Bratus, SETA: Jorge Buenfil (I2O)

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