Evaluation of Rust for Operating System Development and Porting Key Components of the HermitCore Unikernel

Master's Thesis Presentation

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Agenda

Motivation

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```c
#include <stdio.h>
#include <stdlib.h>
#include <sys/stat.h>

int main(int argc, char* argv[]) {
  char *buf, *filename;
  FILE *fp;
  size_t bytes, len;
  struct stat st;

  switch (argc) {
    case 1:
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    case 2:
      filename = argv[argc];
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      buf = (char*)malloc(len);
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      fp = fopen(filename, "rb");
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    case 3:
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out-of-bounds access

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unchecked return values

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buffer overflow due to missing NUL termination →

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- 29 Lines of Code, with serious bugs in at least 11
  - Assignment = instead of equality comparison ==
  - Buffer overflows
  - File descriptor leak
  - Forgotten braces in multi-line `if`
  - Forgotten `break` in a `switch` statement
  - Forgotten NUL-termination of a string
  - Incorrect argument for format string
  - Memory leak
  - Unchecked cases in a `switch` statement
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- **But compiles warning-free with the default settings of many C compilers!**

Motivation

- Not an unrealistic scenario, and highly security-relevant!
  - David Wheeler, *The Apple goto fail vulnerability*
    Forgotten braces in multi-line `if`
  - Ed Felten, *The Linux Backdoor Attempt of 2003*
    Assignment = instead of equality comparison ==
  - Paul Ducklin, *The break that broke sudo*
    Forgotten `break` in a `switch` statement
  - Yves Younan, *25 Years of Vulnerabilities*
    Buffer overflows and format string problems among the top security issues

Motivation

Is a 46-year-old programming language still the way to go?

The Rust Programming Language

- Mozilla-sponsored programming language developed since 2006, with emphasis on safety and concurrency
- Competitor to C and C++: Compiled systems language with deterministic memory management
- Implements mature features of C and C++, but also from Haskell, OCaml, SML, etc.
  (no backward compatibility necessary)

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  (no backward compatibility necessary)
- **Makes all of the aforementioned code bugs impossible, and many others!**

Some Rust Features

The `str` type

- Combines a buffer and a length
- Guaranteed UTF-8 character encoding
- Bounds-checked at runtime
- Used consistently throughout all of Rust

Some Rust Features

Ownership

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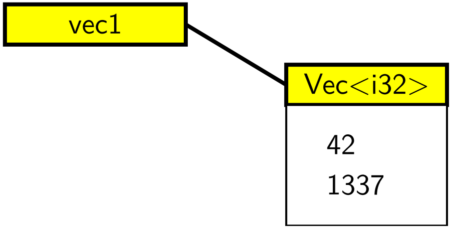
- `let vec1: Vec<i32> = vec![42, 1337];`



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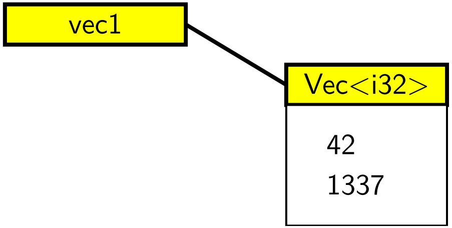

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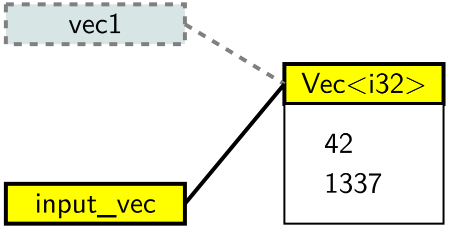

Some Rust Features

References and Borrowing

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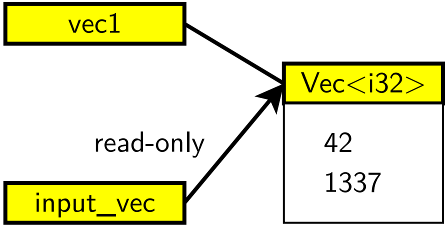
- `fn process_vector(input_vec: &Vec<i32>)`
  - Variable is *borrowed* immutable
  - No transfer of ownership
  - Multiple immutable borrows possible



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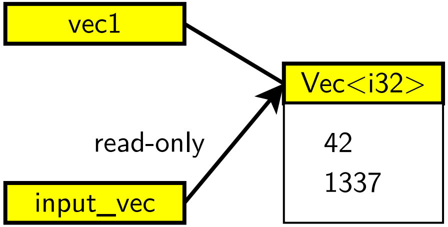
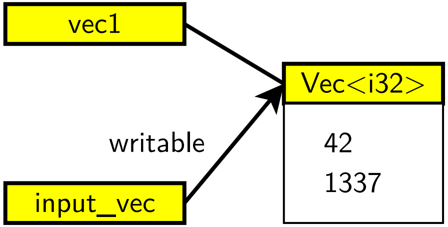
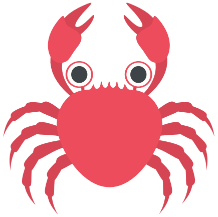


- `fn process_vector(input_vec: &mut Vec<i32>)`
  - Variable is borrowed mutable
  - No transfer of ownership
  - Only one mutable borrow at the same time



The HermitCore Operating System

- Novel operating system kernel developed at the ACS since 2015
- Low system noise and predictable runtime behavior for HPC applications
- Supports GCC (C, C++, Fortran, Go), POSIX, OpenMP, and Pthreads
  - Many existing HPC applications can be easily ported
- Single-address-space library operating system (*Unikernel*)



Thesis Work

Goals

- Porting individual components of HermitCore to Rust while preserving C compatibility
  - Memory Manager
  - x86-64 Hardware Initialization (with APIC and SMP)
  - Scheduler
- Prefer safe and maintainable code over performance during development
- Clean remains of 32-bit x86 specific code in 64-bit x86-64 implementation

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Result

Entire Unikernel mode of HermitCore could be ported within this thesis

By-Products

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  - Not part of the standard Rust library
  - Tricky due to two mutable references per node

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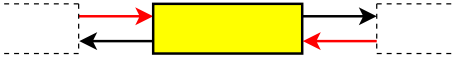

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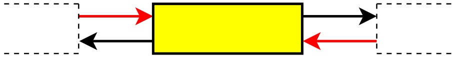

- Generic Free List Implementation
  - Sorted list for managing free blocks of memory
  - Used for both Physical and Virtual Memory Manager
  - Based on Doubly-Linked List

Evaluation

Basic Micro-Benchmarks

System operation	HermitCore Rust	HermitCore C	Linux*
`getpid()`	17	17	143
`sched_yield()`	218	100	370
`malloc()`	764	6080	6575
first write access to a page	27 (4 KiB), 925 (2 MiB)	1407	4007
task switch	5170	934	

in processor cycles

Evaluation

Hourglass Benchmark

	HermitCore Rust	**HermitCore C**	**Linux***
Minimum	24	24	40
Average	30.14	30.15	69.46
Maximum	2551744	5372052	51840

in processor cycles

Evaluation

Code Maintainability

	HermitCore Rust		HermitCore C	
	Files	Lines of Code	Files	Lines of Code
Rust	57	4157	0	0
C Source	8	667	37	5781
C Header	22	866	70	4987
Assembly	6	579	4	932
Sum	**93**	**6269**	**111**	**11700**

Conclusion

- Rust mature enough for operating system development
- Rust increases the productivity
  - Fewer code lines for the same features
  - Compiler catches bugs early
- Added security comes at no significant performance overhead

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- Rust mature enough for operating system development
- Rust increases the productivity
  - Fewer code lines for the same features
  - Compiler catches bugs early
- Added security comes at no significant performance overhead

- **If all our software was written in Rust, most security vulnerabilities would be impossible**

Thank you for your kind attention!

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Some Rust Features

The `Result` type

- Can either be `Ok` or `Err`
- Encapsulates the returned data on success or error information otherwise
- Warning if a `Result` type is returned but not checked