Rust Error Handling

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What's Unique about Rust Error Handling?

- Rust encourages developers to handle every case were errors may occur.

```
30      print!("\n  Please enter some text: ");
31      //let _ = std::io::stdout().flush();
32      std::io::stdout().flush();
33      let rslt = std::io::stdin().read_line(&mut s);
```

```
cargo -q run
warning: unused `std::result::Result` that must be used
  --> src\main.rs:32:5
   |
32 |     std::io::stdout().flush();
   |     ^^^^^^^^^^^^^^^^^^^^^^^^^^
   |
   = note: `#[warn(unused_must_use)]` on by default
   = note: this `Result` may be an `Err` variant, which should be handled
```

- You have to opt out of handling an error case.

```
30      print!("\n  Please enter some text: ");
31      let _ = std::io::stdout().flush();
32      //std::io::stdout().flush();
33      let rslt = std::io::stdin().read_line(&mut s);
```

- Rust has support for bubbling errors up the call chain, creating new custom errors, and returning errors from main.

Errors

- Indexing out of bounds
- Divide by zero
- Integer overflow
- Console and file I/O failures to open or read/write
- Initializing String from non-utf8 byte array
- System and User-defined errors
  - Users supply unexpected or malicious inputs
  - Server not available
  - Unexpected content format

Avoiding Undefined Behavior with Panic

C++ Code

```
47      std::cout << "\n  Demo of Undefined Behavior - out of bounds index";
48      std::cout << "\n ----------------------------------------------
49
50      int array[3]{ 1, 2, 3 };
51      std::cout << "\n  ";
52      for (size_t i = 0; i <= 3; ++i) {
53          std::cout << array[i] << " ";
54      }
55      std::cout << std::endl;
```

Unowned memory can be accessed.
Process ends normally.

```
 Demo of Undefined Behavior - out of bounds index
 ------------------------------------------------
 1 2 3 -858993460

C:\github\JimFawcett\RustModels\Video_1_Introduction\UndefinedB
ehavior\Debug\UndefinedBehavior.exe (process 44608) exited with
 code 0.
Press any key to close this window . . .
```

Rust Code

```
1   use std::io::*;
2
3   fn main() {
4       let array = [1, 2, 3];
5       print!("\n  ");
6       for i in 0..4 {
7           let _ = std::io::stdout().flush();
8           print!("{} ", array[i]);
9       }
10      println!("\n  That's all Folks!\n");
11  }
12
```

```
C:\github\JimFawcett\RustErrorHandling\IndexOutOfBounds>
cargo -q run

  1 2 3 thread 'main' panicked at 'index out of bounds: the l
en is 3 but the index is 3', src\main.rs:8:23
note: run with `RUST_BACKTRACE=1` environment variable to dis
play a backtrace
C:\github\JimFawcett\RustErrorHandling\IndexOutOfBounds>
```

Panic terminates before
memory can be accessed

Rust Panics

- A panic is a program exit that attempts to unwind the stack, dropping each object residing in the stack.
  - Panics can be trapped and handled to avoid program exit
- Should a panic occur while unwinding the stack from an earlier panic the program will immediately abort.
  - Multiple panic aborts cannot be trapped, so stopping in this case is inevitable
- Panics are intended program actions that avoid undefined behavior due to program errors.
  - Indexing out of bounds
- So panics are the lowest level of error handling mechanisms.

Trapping Panics

```rust
fn convert_string_to_int(s:&str) -> i32 {
    // print!("\n  ");
    s.parse::<i32>().unwrap()
}
/*-- traps panic, execution continues --*/
#[allow(dead_code)]
fn trap_panic(f:fn(), name:&str) {
    let default_hook = panic::take_hook();
    set_panic_hook();
    let rslt = panic::catch_unwind(|| f());
    match rslt {
        Ok(()) => print!("{:?} {:?}","successful execution of", name),
        Err(_) => print!("{} paniced", name)
    }
    panic::set_hook(default_hook);
}
/*-----------------------------------------------
   traps panic, execution continues
   - takes function with return value
   - supply input arguments with closure
     - see example at end of main
*/
#[allow(dead_code)]
fn trap_panic_return<F: FnOnce() -> R + UnwindSafe, R>(f:F, name:&str) -> std::io::Result<R>
        where R:Debug + Clone {
    let default_hook = panic::take_hook();
    set_panic_hook();
    let rslt = panic::catch_unwind(|| -> R { f() });
    panic::set_hook(default_hook);
    match &rslt {
        Ok(r) => {
            return Ok(r.clone());
        },
        Err(_) => {
            let arg = format!("{:?} panic", name);
            let error = std::io::Error::new(ErrorKind::Other, arg);
            return Err(error);
        }
    }
}
```

```rust
/*-- elides default panic message --*/
#[allow(dead_code)]
fn set_panic_hook() {
    panic::set_hook(Box::new(|_| print!("")));
}
/*-----------------------------------------------
   tests some of the many ways to panic
   - view a case by uncommenting
*/
fn main() {
    print!("\n  {}","-- testing panics --");
    let _ = std::io::stdout().flush();
    //do_panic();
    //trap_panic(do_panic, "do_panic()");
    //index_out_of_bounds();
    //trap_panic(index_out_of_bounds, "index_out_of_bounds()");
    //divide_by_zero();
    //trap_panic(divide_by_zero, "divide_by_zero()");
    //integer_overflow();
    //trap_panic(integer_overflow, "integer_overflow");
    //initialize_str_with_non_utf8();
    // let fp = initialize_str_with_non_utf8;
    // trap_panic(fp, "initialize_str_with_non_utf8");
    // convert_string_to_int("3.5");
    // -----------------------------------------
    // trap panic for string to int conversion
    let s = String::from("-3");
    //let s = String::from("-3.5");
    let l = || -> i32 { convert_string_to_int(&s) };
    let name = "convert_string_to_int";
    let rslt = trap_panic_return(l, name);
    if rslt.is_ok() {
        print!("\n  {:?}\n  returned {}", name, rslt.unwrap());
    }
    else {
        print!("\n  {}", rslt.unwrap_err());
    }
    //-----------------------------------------
    println!("\n\n  That's all Folks!\n");
}
```

Rust Error Handling Types

- Enum Result<T,E> { Ok(T), Err(E) }
  - #[must_use]
  - std crate import
- pub fn is_ok(&self) -> bool
- pub fn is_Err(&self) -> bool
- pub fn unwrap(self) -> T
  - panics if not Ok
- Pub fn unwrap_err(self) -> E
  - Panics if not Err

Using Result<T,E> with is_ok()

```
36      print!("\n  --- testing output string ---");
37      let _valid = vec![0x61, 0x62, 0x63];
38      let _invalid = vec![0xED, 0xA0, 0x80];
39      let arg = _invalid;
40      /*-- to see both cases try _valid and _invalid --*/
41      let _result;
42      let cvt_str_rslt = String::from_utf8(arg);
43      if cvt_str_rslt.is_ok() {
44          let s:String = cvt_str_rslt.unwrap();
45          let bytes = s.as_bytes();
46          std::io::stdout().write_all(b"\n  writing: ")?;
47          std::io::stdout().write_all(&bytes)?;
48          _result = Ok(());
49      }
50      else {
51          let error = cvt_str_rslt.unwrap_err();
52          print!("\n  {}", error);
53          _result = Err(std::io::Error::new(ErrorKind::Other, "error"));
54      }
```

Illustrates accepting Result<String, FromUtf8Error>, testing, and returning Result<(), CustomError>

Error Types

- Std Error
  - type Result<T> = Result<T,std::io::Error>;
  - std::io crate import
- Custom Error
  - Use std::io::{Error, ErrorKind};
  - Let custom_error =
    Error::new(ErrorKind::Other, some_useful_value);

Error Handling that Avoids Panics

- Each function that can fail should return a std::result::Result<T, E>
  - `fn f<T, E>() -> Result<T, E> { /* code that can fail */ }`
  - std library functions do this and so should user-defined functions
- Result is an enumeration
  - `Enum Result<T, E> { Ok(T), Err(E), }`
  - Returned Result instance is either `Ok(t:T)` or `Err(e:E)`
    - t is the computed value of f()
    - e is the instance of error encountered, either from Error enumeration or user-defined
- Testing Result
  - `let rslt = f();`
  - `if rslt.is_ok() { let t:T = rslt.unwrap();  /* do something with t */ }`
  - `if rslt.is_err() { let e:E = rslt.unwrap_err();  /* do something with e */ }`

Evaluating Result by Matching

- `let rslt = f();`
- ```
  match rslt {
       Ok(t) => { /* do something with t */ },
       Err(e) => { /* do something with e */ },
  }
  ```
- match is required to define actions for both possible results
- if let uses matching operator =
- ```
  if let Ok(t) = rslt {
       /* do something with t = rslt.unwrap() */
  }
  else {
       /* do something with e = rslt.unwrap_err() */
  }
  ```

Demonstration code using match and let if

```
51      /*-- uses match --*/
52      let rslt = always_fails();
53      print!("\n\n  using match:");
54      match rslt {
55          Ok(()) => print!("\n  function always_fails succeeded!\n"),
56          Err(error) => {
57              print!("\n  function always_fails failed");
58              print!("\n    - error message: {:?}\n", error.msg)
59          }
60      }
61      let _ = std::io::stdout().flush();
62
63      /*-- uses if let --*/
64      let _rslt = always_fails();
65      print!("\n  using if let:");
66      /*--  "=" is match operator, not assignment --*/
67      if let Ok(()) = _rslt {
68          print!("\n  function always_fails succeeded");
69      }
70      else {
71          let error:CustomError = _rslt.unwrap_err();
72          print!("\n  function always_fails failed with message:\n  {:#?}", error.msg);
73      }
74      let _ = std::io::stdout().flush();
```

match requires testing both cases, Ok and Err

if let doesn't require handling both cases, but the code may do so, as shown

Bubbling Errors up Call Chain

- `Fn g<T, E>() -> Result<T, E>`
- `Fn f<T, E>() -> Result<T, E> {`

```
    // code elided
    let t:T = g()?
    // code using t elided
}
```

- If g() returns an error the try operator ? returns from f(), passing out the Result object, Err(e:E).
- Otherwise, the ? operator unwraps the result, t:T and binds to t.

Bubbling Errors up the Call Chain

```
28  #[allow(dead_code)]
29  fn always_fails() -> std::result::Result<(),CustomError> {
30      let error = CustomError::new("failure test");
31      Err(error)  // return error
32  }
33  #[allow(dead_code)]
34  fn always_succeeds() -> std::result::Result<(),CustomError> {
35      Ok(())      // return unit result
36  }
```

```
76      /*-- uses try operator ? to bubble up error --*/
77      print!("\n\n  using try operator ?\n");
78      always_fails()?;
79
80      println!("\n\n  That's all
81      Ok(())
82  }
```

f<T>() -> Result<T, E>

if Result<T, E> contains Ok(t:T) after evaluating f()
then f()? Evaluates as t = f().unwrap();
if Result<T, E> contains Err(error)
then f()? Returns Result<T, E> to caller

Console I/O – std::io::stdin()

```
26
27      /*-- reading from stdin --*/
28      let mut s=String::new();
29      use std::io::*;
30      print!("\n  Please enter some text: ");
31      let _ = std::io::stdout().flush();
32      let rslt = std::io::stdin().read_line(&mut s);
33      match rslt {
34          Ok(bytes) => {
35              strip_newline(&mut s);
36              print!("\n  you typed {:?} using {} bytes\n", s, bytes);
37          },
38          Err(error) => print!("\n  your input failed with error: {:?}\n", error),
39      }
40
```

Console I/O – std::io::stdout()

```
42      print!("\n  --- testing output string ---");
43      let _valid = vec![0x61, 0x62, 0x63];
44      let _invalid = vec![0xED, 0xA0, 0x80];
45      let arg = _invalid;
46      /*-- to see both cases try _valid and _invalid --*/
47      let _result;
48      let cvt_str_rslt = String::from_utf8(arg);
49      if cvt_str_rslt.is_ok() {
50          let s:String = cvt_str_rslt.unwrap();
51          let bytes = s.as_bytes();
52          std::io::stdout().write_all(b"\n  writing: ")?;
53          std::io::stdout().write_all(&bytes)?;
54          _result = Ok(());
55      }
56      else {
57          let error = cvt_str_rslt.unwrap_err();
58          print!("\n  {}", error);
59          _result = Err(std::io::Error::new(ErrorKind::Other, "console write error"));
60      }
```

arg = _valid

```
--- testing output string ---
writing: abc
```

arg = _invalid

```
--- testing output string ---
invalid utf-8 sequence of 1 bytes
from index 0
```

```
61      ////////////////////////////////////////////////////////
62      // Using _invalid in code below panics at write_all,
63      // never returns Result.
64      //   That is a bug in std::io::stdout() for Windows
65      //--------------------------------------------------------
66      print!("\n\n  --- testing write result ---\n");
67      let _valid = &[0x61, 0x62, 0x63];
68      let _invalid = &[0xED, 0xA0, 0x80];
69      std::io::stdout().write(b"\n  writing: ")?;
70      let arg = _valid;
71      // setting arg = _invalid
72      // results in untrappable panic, e.g., panic while
73      // panicing
74      ////////////////////////////////////////////////////////
75      // The code below traps panics in Rust code, but
76      // apparently not when calling into foreign code,
77      // like Windows console.
78      //--------------------------------------------------------
79      // let _result = panic::catch_unwind(
80      //     || -> std::io::Result<()> {
81      //         {
82      //             std::io::stdout().write_all(arg)
83      //         }
84      //     }
85      // );
86      let _result = std::io::stdout().write_all(arg);
87      if _result.is_err() {
88          let error = _result.unwrap_err();
89          print!("\n  could not write invalid, error: {:?}", error);
90      }
91      else {
92          print!("\n  wrote {:?}", arg);
93      }
94
```

std::io::stdout()

Stdout() on Windows platform does not work well with non-utf8 characters. If you pass a buffer containing non-utf8 byte sequence(s) the program will panic.

Moreover, that panic cannot be trapped because the stack unwinding process results in a second active panic which always calls an immediate abort.

Note that you can **always avoid this problem** by building a String from the byte sequence. That does reliably fail with a Result if any of the bytes can't be represented as part of a utf-8 sequence.

If it doesn't fail, you can safely pass the String, as bytes, to the stdout().write or write_all methods.

Flexible File Open

```
6
7   #[allow(unused_imports)]
8   use std::fs::{File};
9   use std::io::prelude::*;
10
11  #[allow(dead_code)]
12  struct FileOption;
13  impl FileOption {
14      const CREATE:u8 = 1; const APPEND:u8 = 2;
15      const READ:u8 = 4; const WRITE:u8 = 8;
16  }
17
```

```
17
18  fn open_file(file_name:&str, opt: u8) -> std::io::Result<File> {
19      use std::fs::OpenOptions;
20      let mut f = OpenOptions::new();
21      type FO = FileOption;
22      if opt & FO::WRITE != 0 {
23          f.write(true);
24      }
25      if opt & FO::READ != 0 {
26          f.read(true);
27      }
28      if opt & FO::CREATE != 0 {
29          f.create(true);
30      }
31      if opt & FO::APPEND != 0 {
32          f.append(true);
33      }
34      let rslt = f.open(file_name);
35      rslt
36  }
37
```

Syntax of the Rust language does not support bit-masking on enums (which you can do in C++). The reason is that Rust enums may have any associated type, not just integers (like C++). This code illustrates one way to accomplish bit masking on options.

File Error Handling

```
37
38  fn main() -> std::io::Result<()> {
39
40      let fn1 = "file1.txt";
41      type FO = FileOption;
42      let rslt = open_file(fn1, FO::WRITE | FO::CREATE | FO::APPEND);
43      if rslt.is_ok() {
44          let mut f1 = rslt.unwrap();
45          f1.write(b"abc")?;
46          print!("\n  open and write {:?} succeeded", fn1);
47      }
48      else {
49          print!("\n  open {:?} failed", fn1)
50      }
51
52      let fn2 = "does_not_exist.txt";
53      let rslt = open_file(fn2, FO::WRITE | FO::APPEND);
54      if rslt.is_ok() {
55          print!("\n  open {:?} no create succeeded", fn2);
56      }
57      else {
58          let error = rslt.unwrap_err();
59          print!("\n  error: {:#?} {:?}", error.kind(), fn2);
60      }
61      // https://blog.yoshuawuyts.com/error-handling-survey/
62
63      println!("\n\n  That's all Folks!\n");
64      Ok(())
65  }
66
```

Two cases are presented here. The first attempts to open a file, and, if it does not exist, will create and open it.

The second case does not attempt to create the file if it does not exist, so will fail if it doesn't exist.

Open errors are managed by examining the open_file function's result. Write failures are handled by bubbling up to the caller – main in this case, so a write error terminates the program with an error message.

Summary

- Rust error handling uses:
  - panics
    - Trapping panics has behavior similar to C++ exception handling
  - std::Result<T,E>
    - Must handle both Ok(t:T) and Err(e:E)
  - Matching
    - Equivalent to manually handling Result, but often less code
  - call-chain error event bubbling
    - Supports chaining calls, e.g., anInstance.f1()?.f2()?.f3()?;
    - Chaining requires each function to return self or &self
- Rust tries to prevent developers from ignoring errors or forgetting to manage them.