

# Implementing the NTFS filesystem in Rust

Reusable code from firmware level up to user-mode

Colin Finck



# SPEAKER INFO



Working on the ReactOS Operating System  
for the past 15 years



Ported the HermitCore Unikernel  
from C to Rust in 2017



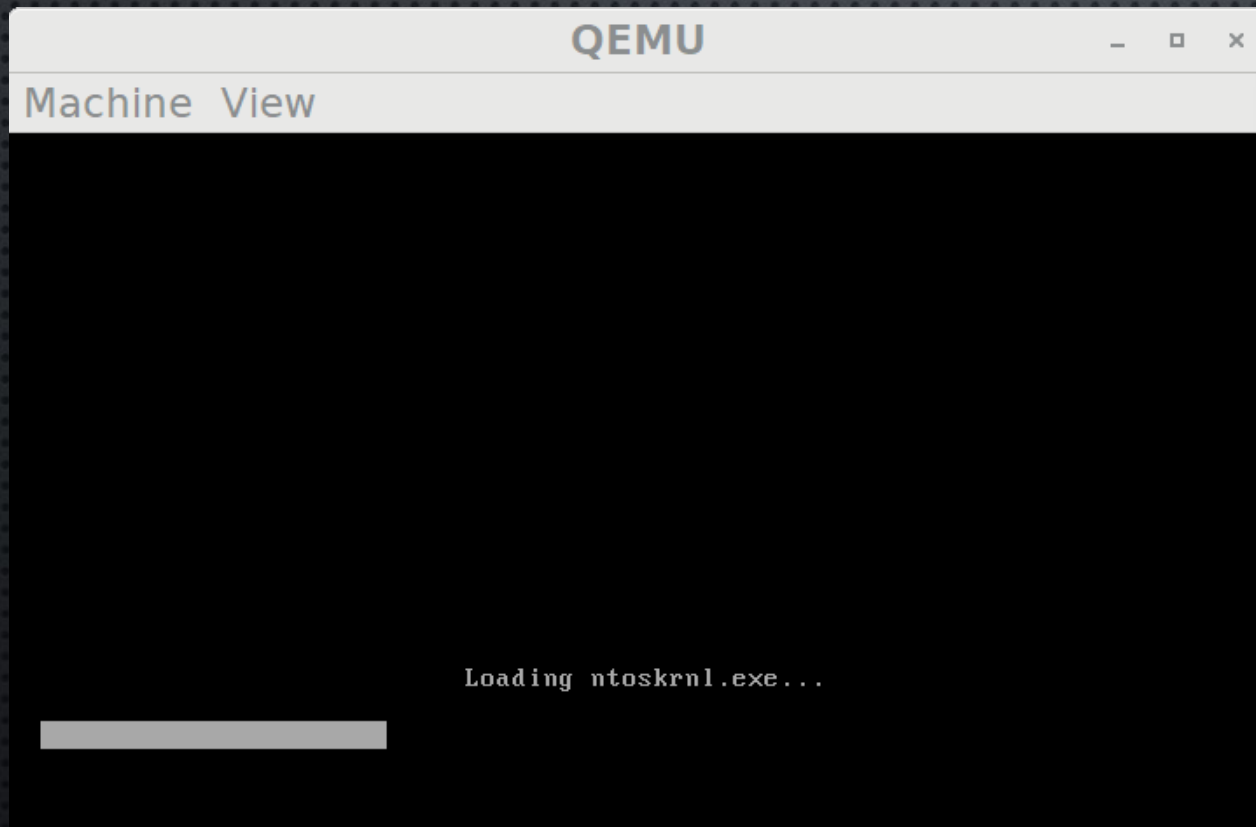
Reverse-Engineering industrial systems  
and writing Rust connectors at ENLYZE



MOTIVATION

# MOTIVATION

Windows / ReactOS bootloader in Rust





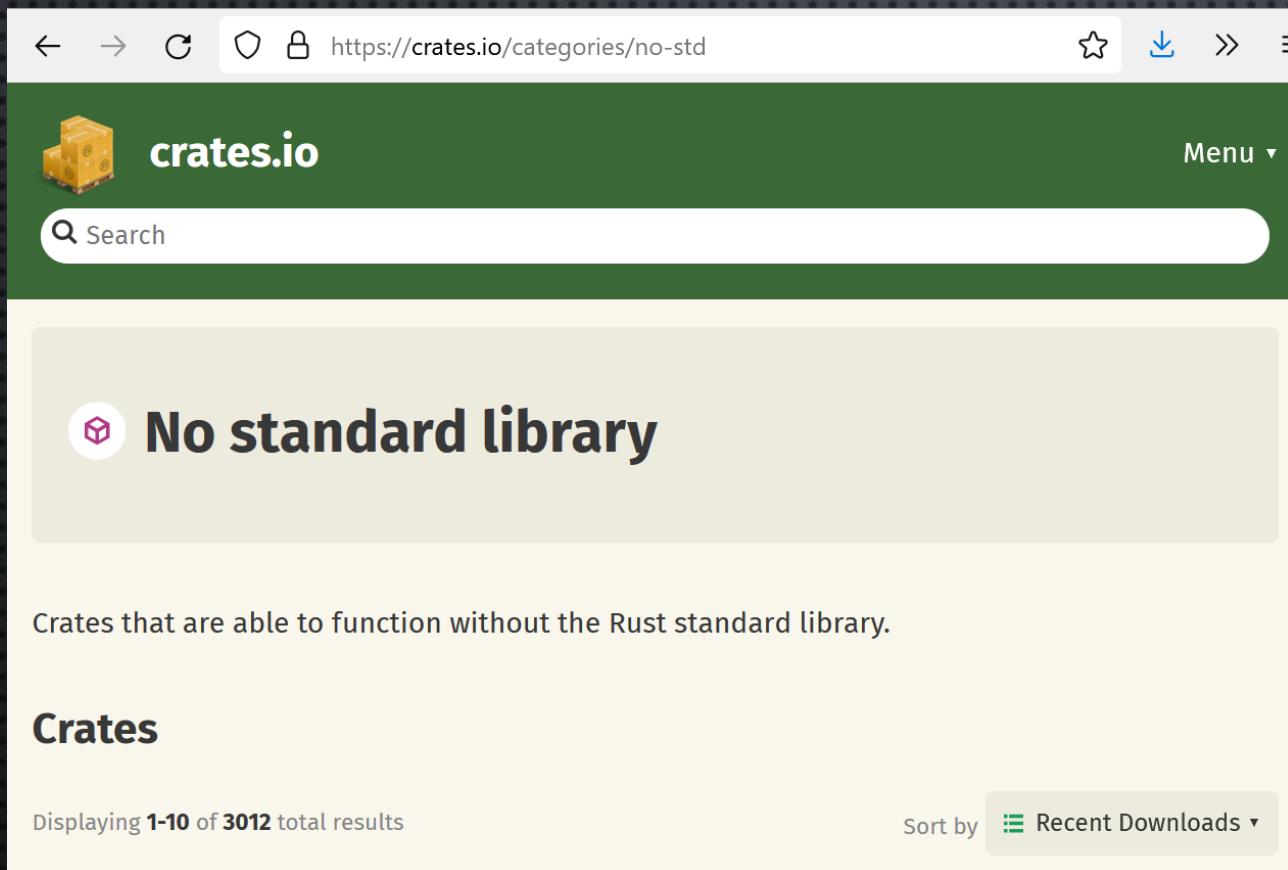
# MOTIVATION

Filesystem support for the growing number of Rust operating systems




# MOTIVATION

## Food for the Rust no\_std ecosystem




The screenshot shows a web browser window with the URL `https://crates.io/categories/no-std`. The page header features the crates.io logo and a search bar. The main content area is titled "No standard library" and includes a description: "Crates that are able to function without the Rust standard library." Below this, the word "Crates" is displayed, followed by the text "Displaying 1-10 of 3012 total results" and a "Sort by" dropdown menu set to "Recent Downloads".

← → ↻ 🔒 `https://crates.io/categories/no-std` ☆ ⬇️ >> ☰

 **crates.io** Menu ▾


🔍 Search

 **No standard library**

Crates that are able to function without the Rust standard library.

**Crates**

Displaying **1-10** of **3012** total results

Sort by  Recent Downloads ▾



# Debian: CVE-2021-33285: ntfs-3g -- security update

← → ↻ 🔍 [https://events.static.linuxfound.org/sites/events/files/slides/AFL filesystem fuzzing%2C Vault 2016\\_0.pdf](https://events.static.linuxfound.org/sites/events/files/slides/AFL%20filesystem%20fuzzing%20Vault%202016_0.pdf) ⬇️ ⏪ ⏩

## Time to first bug

Filesystem	Time	Type
Btrfs	5s	BUG()
Ext4	2h	BUG()
F2fs	10s	BUG()
Gfs2	8m	Double free
Hfs	30s	Page Fault
Hfsplus	25s	Page Fault
Nilfs2	1m	Page Fault
Ntfs	4m	Soft lockup
Ocfs2	15s	BUG()
Reiserfs	25s	BUG()
Xfs	1h45m	Soft lockup

- Linux 4.3 or newer
- 3 AFL instances on my laptop
- Don't believe us?
  - Live crash demo

Sever

CVSS

Publi

Creat

Adde

Modifi

**Severity:** 9

**CVSS:** (AV:N/AC:M/Au:N/C:C/I:C)

**Published:** 06/08/2021

**Created:** 06/09/2021

**Added:** 06/08/2021

**Modified:** 09/14/2021

# Microsoft CVE-2021-33285: Elevation of Privilege

# IMPLEMENTATIONS WITH WRITE SUPPORT

1993

1996

2002

2006

Microsoft Windows

NTFSDOS Professional

Captive NTFS

NTFS-3G

Paragon NTFS

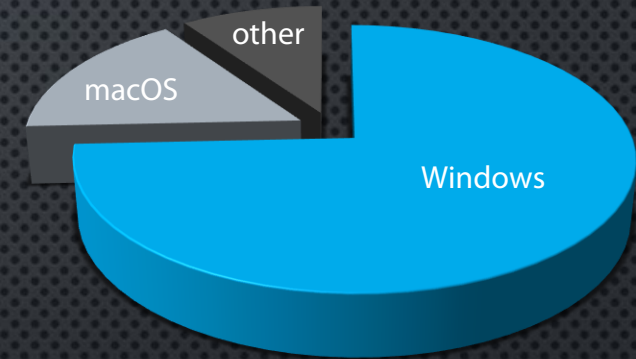


# NTFS FACTS



# NTFS FACTS

- Most popular desktop filesystem
- Initial release 1993, current version 3.1 from 2001
- Unicode filenames
- 64-bit numbers for sizes and timestamps
  - 16 EiB volume and file size, limited to 8 PiB by current Windows
  - Years 1601 – 60056, no Year-2038 problem

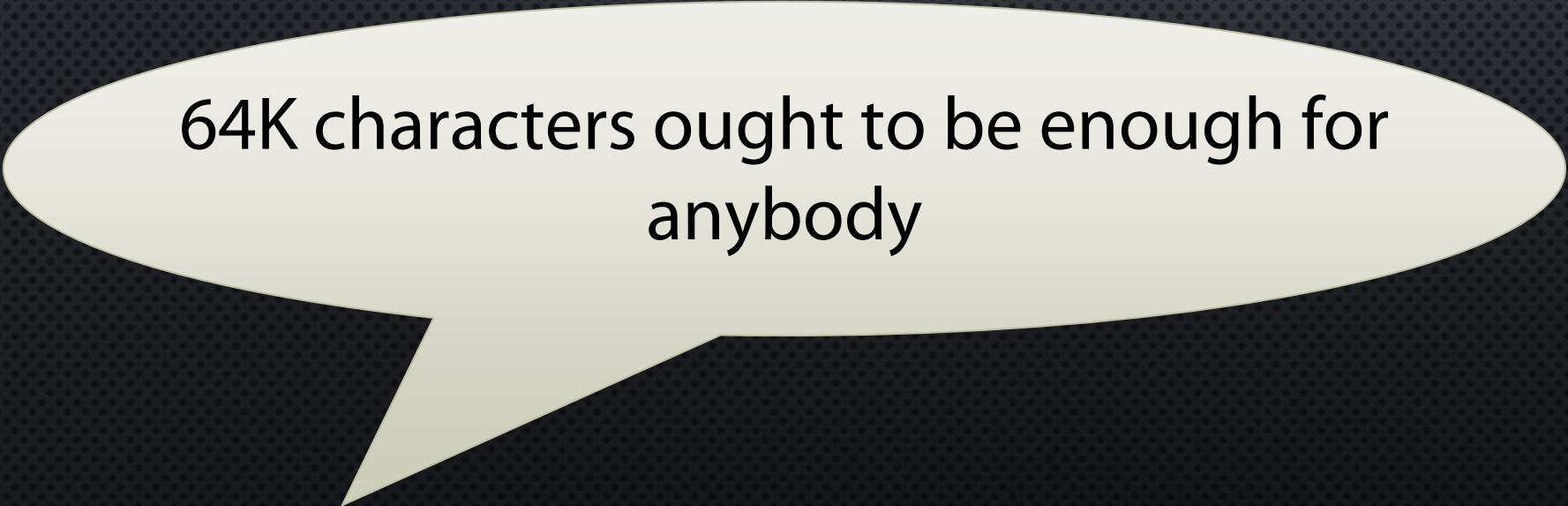


StatCounter Worldwide Desktop Operating System Market Share, November 2021



# NTFS UNICODE STRINGS

- Windows NT first major OS to support Unicode
- Chose UCS-2 fixed-length 2 bytes per character encoding
- Moved to UTF-16 with Windows 2000



64K characters ought to be enough for anybody

# NTFS UNICODE STRINGS

```
struct NtfsString<'a>(&'a [u8])

impl<'a> Display for NtfsString<'a>
impl<'a> Eq for NtfsString<'a>
impl<'a> Ord for NtfsString<'a>

impl<'a> PartialEq<&str> for NtfsString<'a>
impl<'a> PartialEq<NtfsString<'a>> for &str
impl<'a> PartialOrd<&str> for NtfsString<'a>
impl<'a> PartialOrd<NtfsString<'a>> for &str

fn to_string_checked(&self) -> Option<String>
fn to_string_lossy(&self) -> String
```



# NTFS TIMESTAMPS



# Windows epoch

1601





# NTFS TIMESTAMPS

```
struct NtfsTime(u64)

/// Returns the number of 100-nanosecond intervals since January 1, 1601
fn nt_timestamp(&self) -> u64

#[cfg(feature = "chrono")]
impl TryFrom<DateTime<Utc>> for NtfsTime
impl From<NtfsTime> for DateTime<Utc>

#[cfg(feature = "std")]
impl TryFrom<SystemTime> for NtfsTime
```

# NTFS FEATURES

Alternate  
Data Streams

B-Tree  
Indexes

Compression

Encryption

Hard links

Journaling

Quotas

Reparse  
points

Security  
descriptors

Sparse files



# ANATOMY OF AN NTFS FILE

# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA



# FILE Record

\$STANDARD\_INFORMATION

Creation Time

Access Time

Modification Time

Record Modification Time

DOS File Flags

...

\$FILE\_NAME

\$DATA

# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA



# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

Parent Directory Reference

Namespace

Name

...

\$DATA

# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA



# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA

43 6f 6e 67 72 61 74 73

1 KiB

# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA

43 6f 6e 67 72 61 74 73



# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA

43 6f 6e 67 72 61 74 73  
20 59 6f 75 20 66 6f 75

# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA

43 6f 6e 67 72 61 74 73  
20 59 6f 75 20 66 6f 75  
6e 64 20 74 68 65 20 65



# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA

Data Run #0

\$DATA

43	6f	6e	67	72	61	74	73
20	59	6f	75	20	66	6f	75
6e	64	20	74	68	65	20	65

# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA

Data Run #0

\$DATA

43	6f	6e	67	72	61	74	73
20	59	6f	75	20	66	6f	75
6e	64	20	74	68	65	20	65
61	73	74	65	72	20	65	67



# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA

Data Run #0

\$DATA

```
43 6f 6e 67 72 61 74 73
20 59 6f 75 20 66 6f 75
6e 64 20 74 68 65 20 65
61 73 74 65 72 20 65 67
```

# FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA

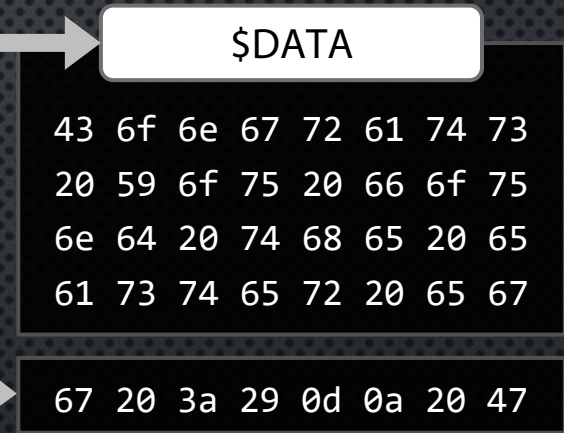
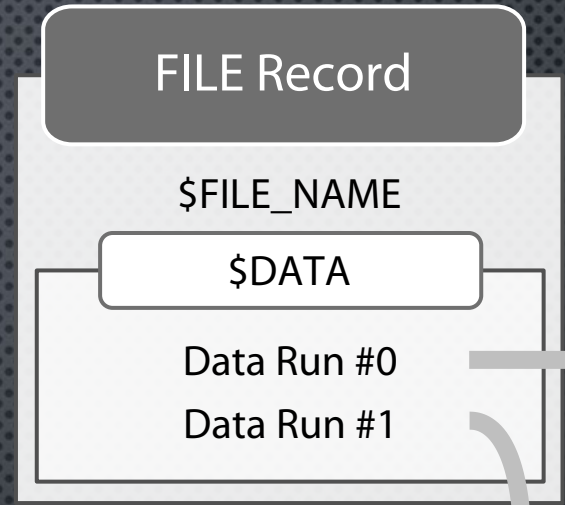
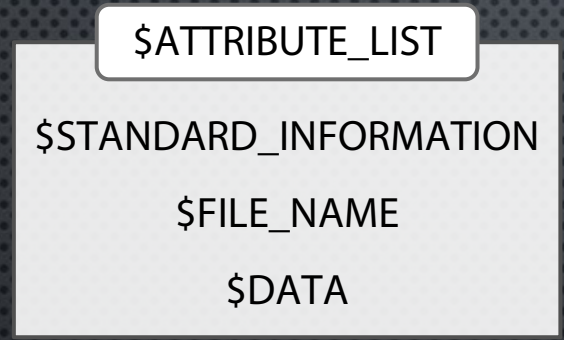
Data Run #0

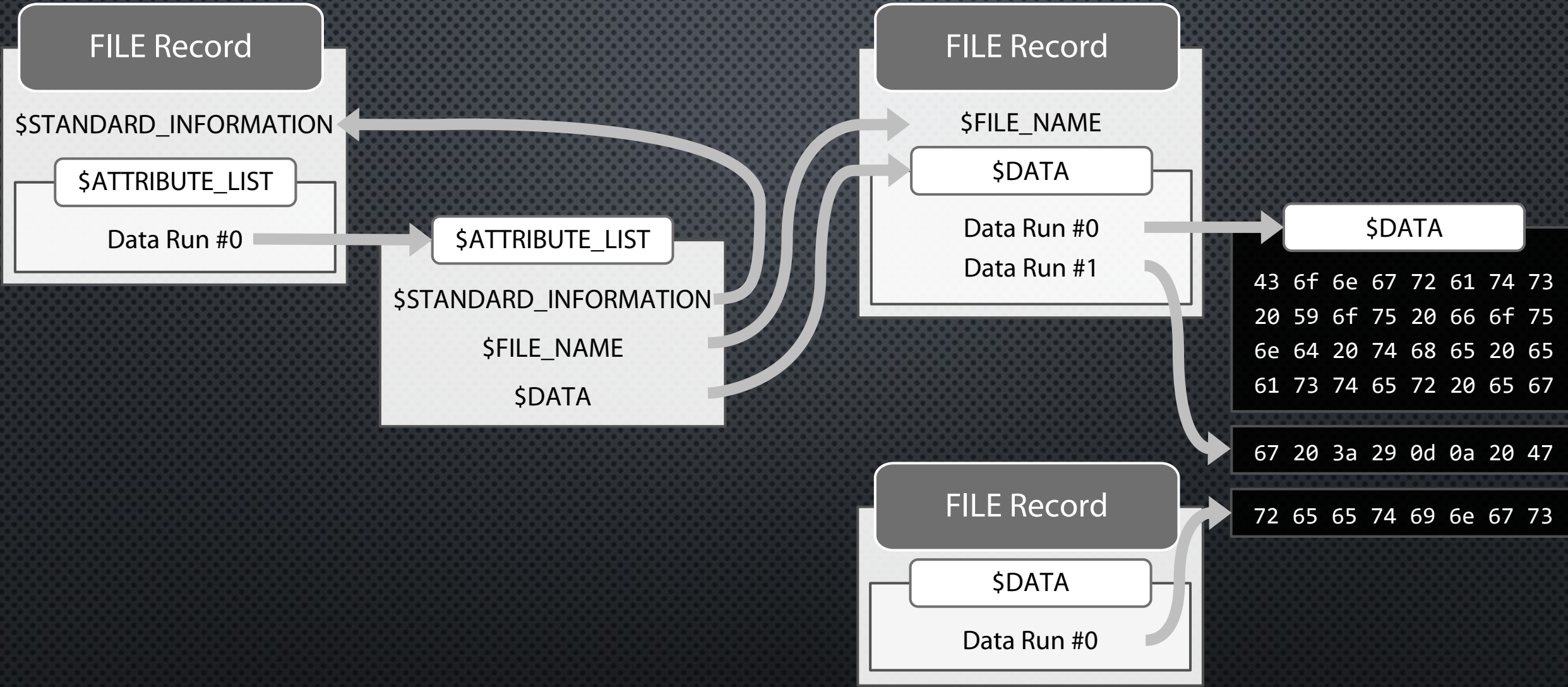
Data Run #1

\$DATA

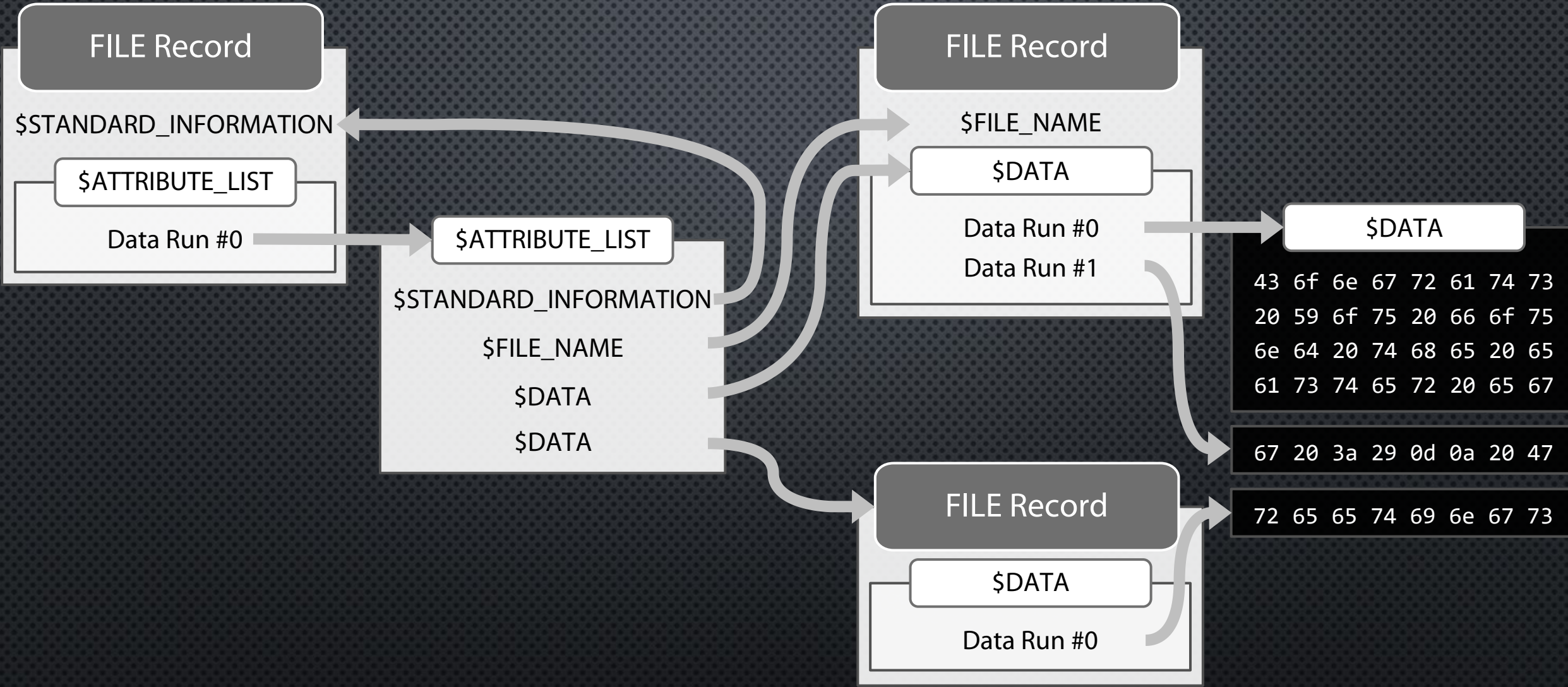
```
43 6f 6e 67 72 61 74 73
20 59 6f 75 20 66 6f 75
6e 64 20 74 68 65 20 65
61 73 74 65 72 20 65 67
```











TRAITS



```
trait Read {
    fn read(&mut self, buf: &mut [u8]) -> Result<usize, std::io::Error>;
}

trait Seek {
    fn seek(&mut self, pos: SeekFrom) -> Result<u64, std::io::Error>;
}
```

```
enum NtfsAttributeValue<'n, 'f> {
    Resident(NtfsResidentAttributeValue<'f>),
    NonResident(NtfsNonResidentAttributeValue<'n, 'f>),
    AttributeListNonResident(...),
}
```

```
trait Read {  
    fn read(&mut self, buf: &mut [u8]) -> Result<usize, std::io::Error>;  
}
```

```
trait Seek {
```

```
struct Error {  
    repr: Repr,  
}
```

```
enum Repr {  
    Os(i32),  
    Simple(ErrorKind),  
    SimpleMessage(ErrorKind, &'static &'static str),  
    Custom(Box<Custom>),  
}
```

```
std::io::Error>;
```



```
trait Read {  
    fn read(&mut self, buf: &mut [u8]) -> Result<usize, std::io::Error>;  
}
```

```
trait Seek {
```

```
struct Error {  
    repr: Repr,  
}
```

```
enum Repr {  
    Os(i32),  
    Simple(ErrorKind),  
    SimpleMessage(ErrorKind, &'static &'static str),  
    Custom(Box<Custom>),  
}
```

```
std::io::Error>;
```

```
trait Read {  
    fn read(&mut self, buf: &mut [u8]) -> Result<usize, binread::io::Error>;  
}  
  
trait Seek {  
    fn seek(&mut self, pos: SeekFrom) -> Result<u64, binread::io::Error>;  
}
```



```
trait Read {  
    fn read(&mut self, buf: &mut [u8]) -> Result<usize, binread::io::Error>;  
}  
  
trait Seek {  
    fn seek(&mut self, pos: SeekFrom) -> Result<u64, binread::io::Error>;  
}
```

```
struct NtfsFile<'a, T: Read + Seek> {  
    fs: &'a mut T,  
}
```



```
struct NtfsFile< a, T: Read + Seek> {  
    fs: &'a mut T,  
}
```

positioned-io crate

```
trait ReadAt {  
    fn read_at(&self, offset: u64, buf: &mut [u8])  
        -> Result<usize>;  
}
```

# ADDITIONAL CONSTRAINTS

- `no_std`  $\Rightarrow$  No OS-specific synchronization



- All borrow checks at compile-time





# 1. Only immutable references in base structs

```
struct Ntfs {  
    cluster_size: u32,  
    sector_size: u16,  
    serial_number: u64,  
}
```

```
struct NtfsFile<'n> {  
    ntfs: &'n Ntfs,  
}
```

## 2. Pass mutable references when needed

```
impl<'n> NtfsFile<'n> {  
    fn data<T>(&self, fs: &mut T) -> ...  
    where  
        T: Read + Seek,  
        { ... }  
}
```



### 3. Provide helper structs with attached mutable reference

```
pub struct NtfsAttributesAttached<'n, 'f, 'a, T: Read + Seek> {  
    fs: &'a mut T,  
    attributes: NtfsAttributes<'n, 'f>,  
}
```

```
impl<'n, 'f, 'a, T> Iterator for NtfsAttributesAttached<'n, 'f, 'a, T>  
where  
    T: Read + Seek,  
{  
    type Item = Result<NtfsAttributeItem<'n, 'f>>;  
  
    fn next(&mut self) -> Option<Self::Item> {  
        self.attributes.next(self.fs)  
    }  
}
```



### 3. Provide helper structs with attached mutable reference

Not an option for

```
fn next<'a, T>(&'a mut self, fs: &mut T) -> Option<Entry<'a>>  
where  
    T: Read + Seek,  
    { ... }
```

Waiting for GATs and StreamingIterator



# RECORD FIXUPS

## FILE Record

\$STANDARD\_INFORMATION

\$FILE\_NAME

\$DATA



# FILE Record

```
46 49 4C 45 30 00 03 00 EF 0B 12 D9 38 00 00 00 1E 00 01 00 38 00 01 00 | FILE0...ï..Ù8.....8...
38 03 00 00 00 04 00 00 00 00 00 00 00 00 00 05 00 00 00 CC F2 24 00 | 8.....Ïð$.
03 00 67 68 00 00 00 00 10 00 00 00 60 00 00 00 00 00 00 00 00 00 | ..gh.....`.....
48 00 00 00 18 00 00 00 6F B6 D8 59 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 | H.....oŸØY$÷x.z.£[$÷x.
7A 94 A3 5B 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 20 00 00 00 00 00 00 00 | z.£[$÷x.z.£[$÷x. ....
00 00 00 00 00 00 00 00 00 00 00 00 EA 0C 00 00 00 00 00 00 00 00 00 | .....ê.....
38 7D A3 07 0E 00 00 00 30 00 00 00 70 00 00 00 00 00 00 00 00 04 00 | 8}£.....θ...p.....
54 00 00 00 18 00 01 00 B6 6E 06 00 00 00 08 00 6F B6 D8 59 24 F7 D7 01 | T.....Ÿn.....oŸØY$÷x.
6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 | oŸØY$÷x.oŸØY$÷x.oŸØY$÷x.
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00 00 00 00 00 00 | .....
09 03 6B 00 61 00 66 00 6B 00 61 00 2E 00 74 00 78 00 74 00 00 00 00 00 | ..k.a.f.k.a...t.x.t.....
80 00 00 00 28 02 00 00 00 00 18 00 00 00 01 00 0C 02 00 00 18 00 00 00 | ....(.....
4F 6E 65 20 6D 6F 72 6E 69 6E 67 2C 20 77 68 65 6E 20 47 72 65 67 6F 72 | One morning, when Gregor
20 53 61 6D 73 61 20 77 6F 6B 65 20 66 72 6F 6D 20 74 72 6F 75 62 6C 65 | Samsa woke from trouble
64 20 64 72 65 61 6D 73 2C 20 68 65 20 66 6F 75 6E 64 20 68 69 6D 73 65 | d dreams, he found himse
6C 66 20 74 72 61 6E 73 66 6F 72 6D 65 64 20 69 6E 20 68 69 73 20 62 65 | lf transformed in his be
64 20 69 6E 74 6F 20 61 20 68 6F 72 72 69 62 6C 65 20 76 65 72 6D 69 6E | d into a horrible vermin
2E 20 48 65 20 6C 61 79 20 6F 6E 20 68 69 73 20 61 72 6D 6F 75 72 2D 6C | . He lay on his armour-l
69 6B 65 20 62 61 63 6B 2C 20 61 6E 64 20 69 66 20 68 65 20 6C 69 66 74 | ike back, and if he lift
65 64 20 68 69 73 20 68 65 61 64 20 61 20 6C 69 74 74 6C 65 20 68 65 20 | ed his head a little he
63 6F 75 6C 64 20 73 65 65 20 68 69 73 20 62 72 6F 77 6E 20 62 65 6C 6C | could see his brown bell
79 2C 20 73 6C 69 03 00 74 6C 79 20 64 6F 6D 65 64 20 61 6E 64 20 64 69 | y, sli..tly domed and di
```



# FILE Record

```
46 49 4C 45 30 00 03 00 EF 0B 12 D9 38 00 00 00 1E 00 01 00 38 00 01 00 | FILE0...ï..Û8.....8...
38 03 00 00 00 04 00 00 00 00 00 00 00 00 00 05 00 00 00 CC F2 24 00 | 8.....Ûð$.
03 00 67 68 00 00 00 00 10 00 00 00 60 00 00 00 00 00 00 00 00 00 00 | ..gh.....`.....
48 00 00 00 18 00 00 00 6F B6 D8 59 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 | H.....oŸØY$÷x.z.ƒ[$÷x.
7A 94 A3 5B 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 20 00 00 00 00 00 00 00 | z.ƒ[$÷x.z.ƒ[$÷x. ....
00 00 00 00 00 00 00 00 00 00 00 00 EA 0C 00 00 00 00 00 00 00 00 00 | .....ê.....
38 7D A3 07 0E 00 00 00 30 00 00 00 70 00 00 00 00 00 00 00 00 04 00 | 8}ƒ.....θ...p.....
54 00 00 00 18 00 01 00 B6 6E 06 00 00 00 08 00 6F B6 D8 59 24 F7 D7 01 | T.....Ÿn.....oŸØY$÷x.
6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 | oŸØY$÷x.oŸØY$÷x.oŸØY$÷x.
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00 00 00 00 00 00 | .....
09 03 6B 00 61 00 66 00 6B 00 61 00 2E 00 74 00 78 00 74 00 00 00 00 | ..k.a.f.k.a...t.x.t.....
80 00 00 00 28 02 00 00 00 00 18 00 00 00 01 00 0C 02 00 00 18 00 00 | ....(.....
4F 6E 65 20 6D 6F 72 6E 69 6E 67 2C 20 77 68 65 6E 20 47 72 65 67 6F 72 | One morning, when Gregor
20 53 61 6D 73 61 20 77 6F 6B 65 20 66 72 6F 6D 20 74 72 6F 75 62 6C 65 | Samsa woke from trouble
64 20 64 72 65 61 6D 73 2C 20 68 65 20 66 6F 75 6E 64 20 68 69 6D 73 65 | d dreams, he found himse
6C 66 20 74 72 61 6E 73 66 6F 72 6D 65 64 20 69 6E 20 68 69 73 20 62 65 | lf transformed in his be
64 20 69 6E 74 6F 20 61 20 68 6F 72 72 69 62 6C 65 20 76 65 72 6D 69 6E | d into a horrible vermin
2E 20 48 65 20 6C 61 79 20 6F 6E 20 68 69 73 20 61 72 6D 6F 75 72 2D 6C | . He lay on his armour-l
69 6B 65 20 62 61 63 6B 2C 20 61 6E 64 20 69 66 20 68 65 20 6C 69 66 74 | ike back, and if he lift
65 64 20 68 69 73 20 68 65 61 64 20 61 20 6C 69 74 74 6C 65 20 68 65 20 | ed his head a little he
63 6F 75 6C 64 20 73 65 65 20 68 69 73 20 62 72 6F 77 6E 20 62 65 6C 6C | could see his brown bell
79 2C 20 73 6C 69 03 00 74 6C 79 20 64 6F 6D 65 64 20 61 6E 64 20 64 69 | y, sli..tly domed and di
```

Header



# FILE Record

```
46 49 4C 45 30 00 03 00 EF 0B 12 D9 38 00 00 00 1E 00 01 00 38 00 01 00 | FILE0...ï..Ù8.....8...
38 03 00 00 00 04 00 00 00 00 00 00 00 00 00 05 00 00 00 CC F2 24 00 | 8.....Ïð$.
03 00 67 68 00 00 00 00 10 00 00 00 60 00 00 00 00 00 00 00 00 00 00 | ..gh.....`.....
48 00 00 00 18 00 00 00 6F B6 D8 59 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 | H.....oŸØY$÷x.z.£[$÷x.
7A 94 A3 5B 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 20 00 00 00 00 00 00 00 | z.£[$÷x.z.£[$÷x. ....
00 00 00 00 00 00 00 00 00 00 00 00 EA 0C 00 00 00 00 00 00 00 00 00 | .....ê.....
38 7D A3 07 0E 00 00 00 30 00 00 00 70 00 00 00 00 00 00 00 00 04 00 | 8}£.....ø...p.....
54 00 00 00 18 00 01 00 B6 6E 06 00 00 00 08 00 6F B6 D8 59 24 F7 D7 01 | T.....Ÿn.....oŸØY$÷x.
6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 | oŸØY$÷x.oŸØY$÷x.oŸØY$÷x.
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00 00 00 00 00 00 | .....
09 03 6B 00 61 00 66 00 6B 00 61 00 2E 00 74 00 78 00 74 00 00 00 00 00 | ..k.a.f.k.a...t.x.t.....
80 00 00 00 28 02 00 00 00 00 18 00 00 00 01 00 0C 02 00 00 18 00 00 00 | ....(.....
4F 6E 65 20 6D 6F 72 6E 69 6E 67 2C 20 77 68 65 6E 20 47 72 65 67 6F 72 | One morning, when Gregor
20 53 61 6D 73 61 20 77 6F 6B 65 20 66 72 6F 6D 20 74 72 6F 75 62 6C 65 | Samsa woke from trouble
64 20 64 72 65 61 6D 73 2C 20 68 65 20 66 6F 75 6E 64 20 68 69 6D 73 65 | d dreams, he found himse
6C 66 20 74 72 61 6E 73 66 6F 72 6D 65 64 20 69 6E 20 68 69 73 20 62 65 | lf transformed in his be
64 20 69 6E 74 6F 20 61 20 68 6F 72 72 69 62 6C 65 20 76 65 72 6D 69 6E | d into a horrible vermin
2E 20 48 65 20 6C 61 79 20 6F 6E 20 68 69 73 20 61 72 6D 6F 75 72 2D 6C | . He lay on his armour-l
69 6B 65 20 62 61 63 6B 2C 20 61 6E 64 20 69 66 20 68 65 20 6C 69 66 74 | ike back, and if he lift
65 64 20 68 69 73 20 68 65 61 64 20 61 20 6C 69 74 74 6C 65 20 68 65 20 | ed his head a little he
63 6F 75 6C 64 20 73 65 65 20 68 69 73 20 62 72 6F 77 6E 20 62 65 6C 6C | could see his brown bell
79 2C 20 73 6C 69 03 00 74 6C 79 20 64 6F 6D 65 64 20 61 6E 64 20 64 69 | y, sli..tly domed and di
```

\$STANDARD\_INFORMATION



# FILE Record

```
46 49 4C 45 30 00 03 00 EF 0B 12 D9 38 00 00 00 1E 00 01 00 38 00 01 00 | FILE0...ï..Ù8.....8...
38 03 00 00 00 04 00 00 00 00 00 00 00 00 00 05 00 00 00 CC F2 24 00 | 8.....Ïð$.
03 00 67 68 00 00 00 00 10 00 00 00 60 00 00 00 00 00 00 00 00 00 00 | ..gh.....`.....
48 00 00 00 18 00 00 00 6F B6 D8 59 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 | H.....oŸØY$÷x.z.ƒ[$÷x.
7A 94 A3 5B 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 20 00 00 00 00 00 00 00 | z.ƒ[$÷x.z.ƒ[$÷x. ....
00 00 00 00 00 00 00 00 00 00 00 00 EA 0C 00 00 00 00 00 00 00 00 00 | .....ê.....
38 7D A3 07 0E 00 00 00 30 00 00 00 70 00 00 00 00 00 00 00 00 00 04 00 | 8}ƒ.....ø...p.....
54 00 00 00 18 00 01 00 B6 6E 06 00 00 00 08 00 6F B6 D8 59 24 F7 D7 01 | T.....Ÿn.....oŸØY$÷x.
6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 | oŸØY$÷x.oŸØY$÷x.oŸØY$÷x.
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00 00 00 00 00 00 | .....
09 03 6B 00 61 00 66 00 6B 00 61 00 2E 00 74 00 78 00 74 00 00 00 00 00 | ..k.a.f.k.a...t.x.t.....
80 00 00 00 28 02 00 00 00 00 18 00 00 00 01 00 0C 02 00 00 18 00 00 00 | ....(.....
4F 6E 65 20 6D 6F 72 6E 69 6E 67 2C 20 77 68 65 6E 20 47 72 65 67 6F 72 | One morning, when Gregor
20 53 61 6D 73 61 20 77 6F 6B 65 20 66 72 6F 6D 20 74 72 6F 75 62 6C 65 | Samsa woke from trouble
64 20 64 72 65 61 6D 73 2C 20 68 65 20 66 6F 75 6E 64 20 68 69 6D 73 65 | d dreams, he found himse
6C 66 20 74 72 61 6E 73 66 6F 72 6D 65 64 20 69 6E 20 68 69 73 20 62 65 | lf transformed in his be
64 20 69 6E 74 6F 20 61 20 68 6F 72 72 69 62 6C 65 20 76 65 72 6D 69 6E | d into a horrible vermin
2E 20 48 65 20 6C 61 79 20 6F 6E 20 68 69 73 20 61 72 6D 6F 75 72 2D 6C | . He lay on his armour-l
69 6B 65 20 62 61 63 6B 2C 20 61 6E 64 20 69 66 20 68 65 20 6C 69 66 74 | ike back, and if he lift
65 64 20 68 69 73 20 68 65 61 64 20 61 20 6C 69 74 74 6C 65 20 68 65 20 | ed his head a little he
63 6F 75 6C 64 20 73 65 65 20 68 69 73 20 62 72 6F 77 6E 20 62 65 6C 6C | could see his brown bell
79 2C 20 73 6C 69 03 00 74 6C 79 20 64 6F 6D 65 64 20 61 6E 64 20 64 69 | y, sli..tly domed and di
```

\$FILE\_NAME



# FILE Record

```
46 49 4C 45 30 00 03 00 EF 0B 12 D9 38 00 00 00 1E 00 01 00 38 00 01 00 | FILE0...ï..Ù8.....8...
38 03 00 00 00 04 00 00 00 00 00 00 00 00 00 05 00 00 00 CC F2 24 00 | 8.....Ïð$.
03 00 67 68 00 00 00 00 10 00 00 00 60 00 00 00 00 00 00 00 00 00 00 | ..gh.....`.....
48 00 00 00 18 00 00 00 6F B6 D8 59 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 | H.....oÿøY$÷x.z.£[$÷x.
7A 94 A3 5B 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 20 00 00 00 00 00 00 00 | z.£[$÷x.z.£[$÷x. ....
00 00 00 00 00 00 00 00 00 00 00 00 EA 0C 00 00 00 00 00 00 00 00 00 | .....ê.....
38 7D A3 07 0E 00 00 00 30 00 00 00 70 00 00 00 00 00 00 00 00 04 00 | 8}£.....ø...p.....
54 00 00 00 18 00 01 00 B6 6E 06 00 00 00 08 00 6F B6 D8 59 24 F7 D7 01 | T.....ŋn.....oÿøY$÷x.
6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 | oÿøY$÷x.oÿøY$÷x.oÿøY$÷x.
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00 00 00 00 00 00 | .....
09 03 6B 00 61 00 66 00 6B 00 61 00 2E 00 74 00 78 00 74 00 00 00 00 00 | ..k.a.f.k.a...t.x.t.....
80 00 00 00 28 02 00 00 00 00 18 00 00 00 01 00 0C 02 00 00 18 00 00 00 | ....(.....
4F 6E 65 20 6D 6F 72 6E 69 6E 67 2C 20 77 68 65 6E 20 47 72 65 67 6F 72 | One morning, when Gregor
20 53 61 6D 73 61 20 77 6F 6B 65 20 66 72 6F 6D 20 74 72 6F 75 62 6C 65 | Samsa woke from trouble
64 20 64 72 65 61 6D 73 2C 20 68 65 20 66 6F 75 6E 64 20 68 69 6D 73 65 | d dreams, he found himse
6C 66 20 74 72 61 6E 73 66 6F 72 6D 65 64 20 69 6E 20 68 69 73 20 62 65 | lf transformed in his be
64 20 69 6E 74 6F 20 61 20 68 6F 72 72 69 62 6C 65 20 76 65 72 6D 69 6E | d into a horrible vermin
2E 20 48 65 20 6C 61 79 20 6F 6E 20 68 69 73 20 61 72 6D 6F 75 72 2D 6C | . He lay on his armour-l
69 6B 65 20 62 61 63 6B 2C 20 61 6E 64 20 69 66 20 68 65 20 6C 69 66 74 | ike back, and if he lift
65 64 20 68 69 73 20 68 65 61 64 20 61 20 6C 69 74 74 6C 65 20 68 65 20 | ed his head a little he
63 6F 75 6C 64 20 73 65 65 20 68 69 73 20 62 72 6F 77 6E 20 62 65 6C 6C | could see his brown bell
79 2C 20 73 6C 69 03 00 74 6C 79 20 64 6F 6D 65 64 20 61 6E 64 20 64 69 | y, sli..tly domed and di
```

\$DATA



# FILE Record

```
46 49 4C 45 30 00 03 00 EF 0B 12 D9 38 00 00 00 1E 00 01 00 38 00 01 00 | FILE0...ï..Ù8.....8...
38 03 00 00 00 04 00 00 00 00 00 00 00 00 00 05 00 00 00 CC F2 24 00 | 8.....Ïð$.
03 00 67 68 00 00 00 00 10 00 00 00 60 00 00 00 00 00 00 00 00 00 00 | ..gh.....`.....
48 00 00 00 18 00 00 00 6F B6 D8 59 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 | H.....oÿøY$÷x.z.f[$÷x.
7A 94 A3 5B 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 20 00 00 00 00 00 00 00 | z.f[$÷x.z.f[$÷x. ....
00 00 00 00 00 00 00 00 00 00 00 00 EA 0C 00 00 00 00 00 00 00 00 00 | .....ê.....
38 7D A3 07 0E 00 00 00 30 00 00 00 70 00 00 00 00 00 00 00 00 04 00 | 8}f.....ø...p.....
54 00 00 00 18 00 01 00 B6 6E 06 00 00 00 08 00 6F B6 D8 59 24 F7 D7 01 | T.....ŋn.....oÿøY$÷x.
6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 | oÿøY$÷x.oÿøY$÷x.oÿøY$÷x.
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00 00 00 00 00 00 | .....
09 03 6B 00 61 00 66 00 6B 00 61 00 2E 00 74 00 78 00 74 00 00 00 00 00 | ..k.a.f.k.a...t.x.t.....
80 00 00 00 28 02 00 00 00 00 18 00 00 00 01 00 0C 02 00 00 18 00 00 00 | ....(.....
4F 6E 65 20 6D 6F 72 6E 69 6E 67 2C 20 77 68 65 6E 20 47 72 65 67 6F 72 | One morning, when Gregor
20 53 61 6D 73 61 20 77 6F 6B 65 20 66 72 6F 6D 20 74 72 6F 75 62 6C 65 | Samsa woke from trouble
64 20 64 72 65 61 6D 73 2C 20 68 65 20 66 6F 75 6E 64 20 68 69 6D 73 65 | d dreams, he found himse
6C 66 20 74 72 61 6E 73 66 6F 72 6D 65 64 20 69 6E 20 68 69 73 20 62 65 | lf transformed in his be
64 20 69 6E 74 6F 20 61 20 68 6F 72 72 69 62 6C 65 20 76 65 72 6D 69 6E | d into a horrible vermin
2E 20 48 65 20 6C 61 79 20 6F 6E 20 68 69 73 20 61 72 6D 6F 75 72 2D 6C | . He lay on his armour-l
69 6B 65 20 62 61 63 6B 2C 20 61 6E 64 20 69 66 20 68 65 20 6C 69 66 74 | ike back, and if he lift
65 64 20 68 69 73 20 68 65 61 64 20 61 20 6C 69 74 74 6C 65 20 68 65 20 | ed his head a little he
63 6F 75 6C 64 20 73 65 65 20 68 69 73 20 62 72 6F 77 6E 20 62 65 6C 6C | could see his brown bell
79 2C 20 73 6C 69 03 00 74 6C 79 20 64 6F 6D 65 64 20 61 6E 64 20 64 69 | y, sli..tly domed and di
```

\$DATA



# FILE Record

```
46 49 4C 45 30 00 03 00 EF 0B 12 D9 38 00 00 00 1E 00 01 00 38 00 01 00 | FILE0...ï..Ù8.....8...
38 03 00 00 00 04 00 00 00 00 00 00 00 00 00 05 00 00 00 CC F2 24 00 | 8.....Ïð$.
03 00 67 68 00 00 00 00 10 00 00 00 60 00 00 00 00 00 00 00 00 00 00 | ..gh.....
48 00 00 00 18 00 00 00 6F B6 D8 59 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 | H.....oŸØY$÷x.z.f[$÷x.
7A 94 A3 5B 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 20 00 00 00 00 00 00 00 | z.f[$÷x.z.f[$÷x. ....
00 00 00 00 00 00 00 00 00 00 00 00 EA 0C 00 00 00 00 00 00 00 00 00 | .....ê.....
38 7D A3 07 0E 00 00 00 30 00 00 00 70 00 00 00 00 00 00 00 00 04 00 | 8}f.....θ...p.....
54 00 00 00 18 00 01 00 B6 6E 06 00 00 00 08 00 6F B6 D8 59 24 F7 D7 01 | T.....Ÿn.....oŸØY$÷x.
6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 | oŸØY$÷x.oŸØY$÷x.oŸØY$÷x.
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00 00 00 00 00 | .....
09 03 6B 00 61 00 66 00 6B 00 61 00 2E 00 74 00 78 00 74 00 00 00 00 00 | ..k.a.f.k.a...t.x.t.....
80 00 00 00 28 02 00 00 00 00 18 00 00 00 01 00 0C 02 00 00 18 00 00 00 | ....(.....
4F 6E 65 20 6D 6F 72 6E 69 6E 67 2C 20 77 68 65 6E 20 47 72 65 67 6F 72 | One morning, when Gregor
20 53 61 6D 73 61 20 77 6F 6B 65 20 66 72 6F 6D 20 74 72 6F 75 62 6C 65 | Samsa woke from trouble
64 20 64 72 65 61 6D 73 2C 20 68 65 20 66 6F 75 6E 64 20 68 69 6D 73 65 | d dreams, he found himse
6C 66 20 74 72 61 6E 73 66 6F 72 6D 65 64 20 69 6E 20 68 69 73 20 62 65 | lf transformed in his be
64 20 69 6E 74 6F 20 61 20 68 6F 72 72 69 62 6C 65 20 76 65 72 6D 69 6E | d into a horrible vermin
2E 20 48 65 20 6C 61 79 20 6F 6E 20 68 69 73 20 61 72 6D 6F 75 72 2D 6C | . He lay on his armour-l
69 6B 65 20 62 61 63 6B 2C 20 61 6E 64 20 69 66 20 68 65 20 6C 69 66 74 | ike back, and if he lift
65 64 20 68 69 73 20 68 65 61 64 20 61 20 6C 69 74 74 6C 65 20 68 65 20 | ed his head a little he
63 6F 75 6C 64 20 73 65 65 20 68 69 73 20 62 72 6F 77 6E 20 62 65 6C 6C | could see his brown bell
79 2C 20 73 6C 69 03 00 74 6C 79 20 64 6F 6D 65 64 20 61 6E 64 20 64 69 | y, sli..tly domed and di
```

Update Sequence

\$DATA



# FILE Record

```
46 49 4C 45 30 00 03 00 EF 0B 12 D9 38 00 00 00 1E 00 01 00 38 00 01 00 | FILE0...ï..Ù8.....8...
38 03 00 00 00 04 00 00 00 00 00 00 00 00 00 05 00 00 00 CC F2 24 00 | 8.....Ïð$.
03 00 67 68 00 00 00 00 10 00 00 00 60 00 00 00 00 00 00 00 00 00 00 | .gh.....
48 00 00 00 18 00 00 00 6F B6 D8 59 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 | H.....oŸØY$÷x.z.f[$÷x.
7A 94 A3 5B 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 20 00 00 00 00 00 00 00 | z.f[$÷x.z.f[$÷x. ....
00 00 00 00 00 00 00 00 00 00 00 00 EA 0C 00 00 00 00 00 00 00 00 00 | .....ê.....
38 7D A3 07 0E 00 00 00 30 00 00 00 70 00 00 00 00 00 00 00 00 04 00 | 8}f.....θ...p.....
54 00 00 00 18 00 01 00 B6 6E 06 00 00 00 08 00 6F B6 D8 59 24 F7 D7 01 | T.....Ÿn.....oŸØY$÷x.
6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 | oŸØY$÷x.oŸØY$÷x.oŸØY$÷x.
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00 00 00 00 00 | .....
09 03 6B 00 61 00 66 00 6B 00 61 00 2E 00 74 00 78 00 74 00 00 00 00 | ..k.a.f.k.a...t.x.t....
80 00 00 00 28 02 00 00 00 00 18 00 00 00 01 00 0C 02 00 00 18 00 00 00 | ....(.....
4F 6E 65 20 6D 6F 72 6E 69 6E 67 2C 20 77 68 65 6E 20 47 72 65 67 6F 72 | One morning, when Gregor
20 53 61 6D 73 61 20 77 6F 6B 65 20 66 72 6F 6D 20 74 72 6F 75 62 6C 65 | Samsa woke from trouble
64 20 64 72 65 61 6D 73 2C 20 68 65 20 66 6F 75 6E 64 20 68 69 6D 73 65 | d dreams, he found himse
6C 66 20 74 72 61 6E 73 66 6F 72 6D 65 64 20 69 6E 20 68 69 73 20 62 65 | lf transformed in his be
64 20 69 6E 74 6F 20 61 20 68 6F 72 72 69 62 6C 65 20 76 65 72 6D 69 6E | d into a horrible vermin
2E 20 48 65 20 6C 61 79 20 6F 6E 20 68 69 73 20 61 72 6D 6F 75 72 2D 6C | . He lay on his armour-l
69 6B 65 20 62 61 63 6B 2C 20 61 6E 64 20 69 66 20 68 65 20 6C 69 66 74 | ike back, and if he lift
65 64 20 68 69 73 20 68 65 61 64 20 61 20 6C 69 74 74 6C 65 20 68 65 20 | ed his head a little he
63 6F 75 6C 64 20 73 65 65 20 68 69 73 20 62 72 6F 77 6E 20 62 65 6C 6C | could see his brown bell
79 2C 20 73 6C 69 03 00 74 6C 79 20 64 6F 6D 65 64 20 61 6E 64 20 64 69 | y, sli..tly domed and di
```

Update Sequence

\$DATA



# FILE Record

```
46 49 4C 45 30 00 03 00 EF 0B 12 D9 38 00 00 00 1E 00 01 00 38 00 01 00 | FILE0...ï..Ù8.....8...
38 03 00 00 00 04 00 00 00 00 00 00 00 00 00 05 00 00 00 CC F2 24 00 | 8.....Ïð$.
03 00 67 68 00 00 00 00 10 00 00 00 60 00 00 00 00 00 00 00 00 00 00 00 | .gh.....
48 00 00 00 18 00 00 00 6F B6 D8 59 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 | H.....oŸØY$÷x.z.ƒ[$÷x.
7A 94 A3 5B 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 20 00 00 00 00 00 00 00 | z.ƒ[$÷x.z.ƒ[$÷x. ....
00 00 00 00 00 00 00 00 00 00 00 00 EA 0C 00 00 00 00 00 00 00 00 00 00 | .....ê.....
38 7D A3 07 0E 00 00 00 30 00 00 00 70 00 00 00 00 00 00 00 00 00 04 00 | 8}ƒ.....θ...p.....
54 00 00 00 18 00 01 00 B6 6E 06 00 00 00 08 00 6F B6 D8 59 24 F7 D7 01 | T.....Ÿn.....oŸØY$÷x.
6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 | oŸØY$÷x.oŸØY$÷x.oŸØY$÷x.
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00 00 00 00 00 00 | .....
09 03 6B 00 61 00 66 00 6B 00 61 00 2E 00 74 00 78 00 74 00 00 00 00 00 | ..k.a.f.k.a...t.x.t.....
80 00 00 00 28 02 00 00 00 00 18 00 00 00 01 00 0C 02 00 00 18 00 00 00 | ....(.....
4F 6E 65 20 6D 6F 72 6E 69 6E 67 2C 20 77 68 65 6E 20 47 72 65 67 6F 72 | One morning, when Gregor
20 53 61 6D 73 61 20 77 6F 6B 65 20 66 72 6F 6D 20 74 72 6F 75 62 6C 65 | Samsa woke from trouble
64 20 64 72 65 61 6D 73 2C 20 68 65 20 66 6F 75 6E 64 20 68 69 6D 73 65 | d dreams, he found himse
6C 66 20 74 72 61 6E 73 66 6F 72 6D 65 64 20 69 6E 20 68 69 73 20 62 65 | lf transformed in his be
64 20 69 6E 74 6F 20 61 20 68 6F 72 72 69 62 6C 65 20 76 65 72 6D 69 6E | d into a horrible vermin
2E 20 48 65 20 6C 61 79 20 6F 6E 20 68 69 73 20 61 72 6D 6F 75 72 2D 6C | . He lay on his armour-l
69 6B 65 20 62 61 63 6B 2C 20 61 6E 64 20 69 66 20 68 65 20 6C 69 66 74 | ike back, and if he lift
65 64 20 68 69 73 20 68 65 61 64 20 61 20 6C 69 74 74 6C 65 20 68 65 20 | ed his head a little he
63 6F 75 6C 64 20 73 65 65 20 68 69 73 20 62 72 6F 77 6E 20 62 65 6C 6C | could see his brown bell
79 2C 20 73 6C 69 03 00 74 6C 79 20 64 6F 6D 65 64 20 61 6E 64 20 64 69 | y, sli..tly domed and di
```

Update Sequence

\$DATA



# FILE Record

```
46 49 4C 45 30 00 03 00 EF 0B 12 D9 38 00 00 00 1E 00 01 00 38 00 01 00 | FILE0...ï..Ù8.....8...
38 03 00 00 00 04 00 00 00 00 00 00 00 00 00 05 00 00 00 CC F2 24 00 | 8.....Ïð$.
03 00 67 68 00 00 00 00 10 00 00 00 60 00 00 00 00 00 00 00 00 00 00 | ..gh.....
48 00 00 00 18 00 00 00 6F B6 D8 59 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 | H.....oŸØY$÷x.z.f[$÷x.
7A 94 A3 5B 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 20 00 00 00 00 00 00 00 | z.f[$÷x.z.f[$÷x. ....
00 00 00 00 00 00 00 00 00 00 00 00 EA 0C 00 00 00 00 00 00 00 00 00 | .....ê.....
38 7D A3 07 0E 00 00 00 30 00 00 00 70 00 00 00 00 00 00 00 00 04 00 | 8}f.....θ...p.....
54 00 00 00 18 00 01 00 B6 6E 06 00 00 00 08 00 6F B6 D8 59 24 F7 D7 01 | T.....Ÿn.....oŸØY$÷x.
6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 | oŸØY$÷x.oŸØY$÷x.oŸØY$÷x.
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00 00 00 00 00 | .....
09 03 6B 00 61 00 66 00 6B 00 61 00 2E 00 74 00 78 00 74 00 00 00 00 | ..k.a.f.k.a...t.x.t....
80 00 00 00 28 02 00 00 00 00 18 00 00 00 01 00 0C 02 00 00 18 00 00 00 | ....(.....
4F 6E 65 20 6D 6F 72 6E 69 6E 67 2C 20 77 68 65 6E 20 47 72 65 67 6F 72 | One morning, when Gregor
20 53 61 6D 73 61 20 77 6F 6B 65 20 66 72 6F 6D 20 74 72 6F 75 62 6C 65 | Samsa woke from trouble
64 20 64 72 65 61 6D 73 2C 20 68 65 20 66 6F 75 6E 64 20 68 69 6D 73 65 | d dreams, he found himse
6C 66 20 74 72 61 6E 73 66 6F 72 6D 65 64 20 69 6E 20 68 69 73 20 62 65 | lf transformed in his be
64 20 69 6E 74 6F 20 61 20 68 6F 72 72 69 62 6C 65 20 76 65 72 6D 69 6E | d into a horrible vermin
2E 20 48 65 20 6C 61 79 20 6F 6E 20 68 69 73 20 61 72 6D 6F 75 72 2D 6C | . He lay on his armour-l
69 6B 65 20 62 61 63 6B 2C 20 61 6E 64 20 69 66 20 68 65 20 6C 69 66 74 | ike back, and if he lift
65 64 20 68 69 73 20 68 65 61 64 20 61 20 6C 69 74 74 6C 65 20 68 65 20 | ed his head a little he
63 6F 75 6C 64 20 73 65 65 20 68 69 73 20 62 72 6F 77 6E 20 62 65 6C 6C | could see his brown bell
79 2C 20 73 6C 69 03 00 74 6C 79 20 64 6F 6D 65 64 20 61 6E 64 20 64 69 | y, sli..tly domed and di
```

Update Sequence

\$DATA



# FILE Record

46 49 4C 45 30 00 03 00 EF 0B 12 D9 38 00 00 00 1E 00 01 00 38 00 01 00	FILE0...ï..Ù8.....8...
38 03 00 00 00 04 00 00 00 00 00 00 00 00 00 05 00 00 00 CC F2 24 00	8.....Ïð\$.
<b>03 00 67 68 00 00 00 00</b> 10 00 00 00 60 00 00 00 00 00 00 00 00 00 00 00 00 00	..gh.....`.....
48 00 00 00 18 00 00 00 6F B6 D8 59 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01	H.....oŸØY\$÷x.z.f[\$÷x.
7A 94 A3 5B 24 F7 D7 01 7A 94 A3 5B 24 F7 D7 01 20 00 00 00 00 00 00 00	z.f[\$÷x.z.f[\$÷x. ....
00 00 00 00 00 00 00 00 00 00 00 00 EA 0C 00 00 00 00 00 00 00 00 00	.....ê.....
38 7D A3 07 0E 00 00 00 30 00 00 00 70 00 00 00 00 00 00 00 00 04 00	8}f.....θ...p.....
54 00 00 00 18 00 01 00 B6 6E 06 00 00 00 08 00 6F B6 D8 59 24 F7 D7 01	T.....Ÿn.....oŸØY\$÷x.
6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01 6F B6 D8 59 24 F7 D7 01	oŸØY\$÷x.oŸØY\$÷x.oŸØY\$÷x.
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00 00 00 00 00 00	..... .....
09 03 6B 00 61 00 66 00 6B 00 61 00 2E 00 74 00 78 00 74 00 00 00 00 00	..k.a.f.k.a...t.x.t.....
<b>80 00 00 00 28 02 00 00 00 00 18 00 00 00 01 00 0C 02 00 00 18 00 00 00</b>	....(.....
4F 6E 65 20 6D 6F 72 6E 69 6E 67 2C 20 77 68 65 6E 20 47 72 65 67 6F 72	One morning, when Gregor
20 53 61 6D 73 61 20 77 6F 6B 65 20 66 72 6F 6D 20 74 72 6F 75 62 6C 65	Samsa woke from trouble
64 20 64 72 65 61 6D 73 2C 20 68 65 20 66 6F 75 6E 64 20 68 69 6D 73 65	d dreams, he found himse
6C 66 20 74 72 61 6E 73 66 6F 72 6D 65 64 20 69 6E 20 68 69 73 20 62 65	lf transformed in his be
64 20 69 6E 74 6F 20 61 20 68 6F 72 72 69 62 6C 65 20 76 65 72 6D 69 6E	d into a horrible vermin
2E 20 48 65 20 6C 61 79 20 6F 6E 20 68 69 73 20 61 72 6D 6F 75 72 2D 6C	. He lay on his armour-l
69 6B 65 20 62 61 63 6B 2C 20 61 6E 64 20 69 66 20 68 65 20 6C 69 66 74	ike back, and if he lift
65 64 20 68 69 73 20 68 65 61 64 20 61 20 6C 69 74 74 6C 65 20 68 65 20	ed his head a little he
63 6F 75 6C 64 20 73 65 65 20 68 69 73 20 62 72 6F 77 6E 20 62 65 6C 6C	could see his brown bell
79 2C 20 73 6C 69 <b>67 68</b> 74 6C 79 20 64 6F 6D 65 64 20 61 6E 64 20 64 69	y, slightly domed and di

Update Sequence

\$DATA

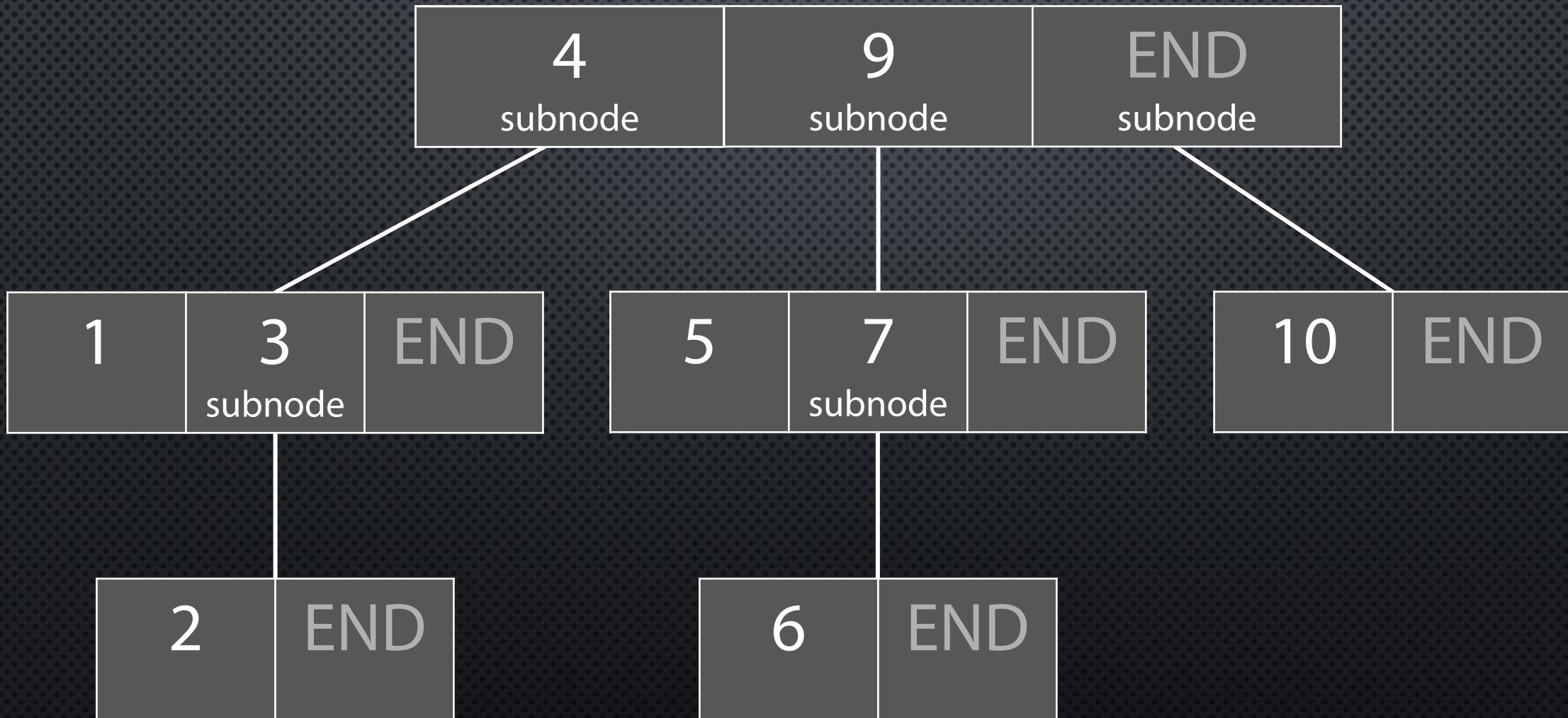
```
pub(crate) struct Record<'n> {  
    ntfs: &'n Ntfs,  
    data: Vec<u8>,  
    position: u64,  
}
```

~~ArrayVec~~



# B-TREE INDEXES

# AN NTFS B-TREE





## Index Entry

Data Offset

Data Length

Padding

Index Entry Length

Key Length

Flags

Key

Data

Subnode

## File Index Entry

File Reference

Index Entry Length

Key Length

Flags

Key

Subnode



## File Index Key

```
30 00 00 00 70 00 00 00 | 0...p...
00 00 00 00 00 00 04 00 | .....
54 00 00 00 18 00 01 00 | T.....
B6 6E 06 00 00 00 08 00 | 9n.....
6F B6 D8 59 24 F7 D7 01 | o90Y$÷x.
6F B6 D8 59 24 F7 D7 01 | o90Y$÷x.
6F B6 D8 59 24 F7 D7 01 | o90Y$÷x.
6F B6 D8 59 24 F7 D7 01 | o90Y$÷x.
00 00 00 00 00 00 00 00 | .....
00 00 00 00 00 00 00 00 | .....
20 00 00 00 00 00 00 00 | .....
09 03 6B 00 61 00 66 00 | ..k.a.f.
6B 00 61 00 2E 00 74 00 | k.a...t.
78 00 74 00 00 00 00 00 | x.t.....
```

**\$FILE\_NAME**

# TRAITS TO THE RESCUE

```
trait NtfsIndexEntryType
```

```
trait NtfsIndexEntryHasData: NtfsIndexEntryType
```

```
trait NtfsIndexEntryHasFileReference: NtfsIndexEntryType
```



# TRAITS TO THE RESCUE

```
trait NtfsIndexEntryType {  
  type KeyType: NtfsIndexEntryKey  
}
```

```
trait NtfsIndexEntryHasData: NtfsIndexEntryType {  
  type DataType: NtfsIndexEntryData  
}
```

```
trait NtfsIndexEntryHasFileReference: NtfsIndexEntryType
```

```
trait NtfsIndexEntryKey
```

```
trait NtfsIndexEntryData
```

# FILE INDEX IMPLEMENTATION

```
struct NtfsFileName {  
    header: FileNameHeader,  
    name: ArrayVec<u8, NAME_MAX_SIZE>,  
}
```

```
impl NtfsIndexEntryKey for NtfsFileName
```

```
struct NtfsFileNameIndex
```

```
impl NtfsIndexEntryType for NtfsFileNameIndex {  
    type KeyType = NtfsFileName  
}
```

```
impl NtfsIndexEntryHasFileReference for NtfsFileNameIndex
```



# GENERIC INDEX IMPLEMENTATION

```
impl<'s, E> NtfsIndexEntry<'s, E>
where
    E: NtfsIndexEntryType,
{

    fn key(&self) -> Option<Result<E::KeyType>> { ... }

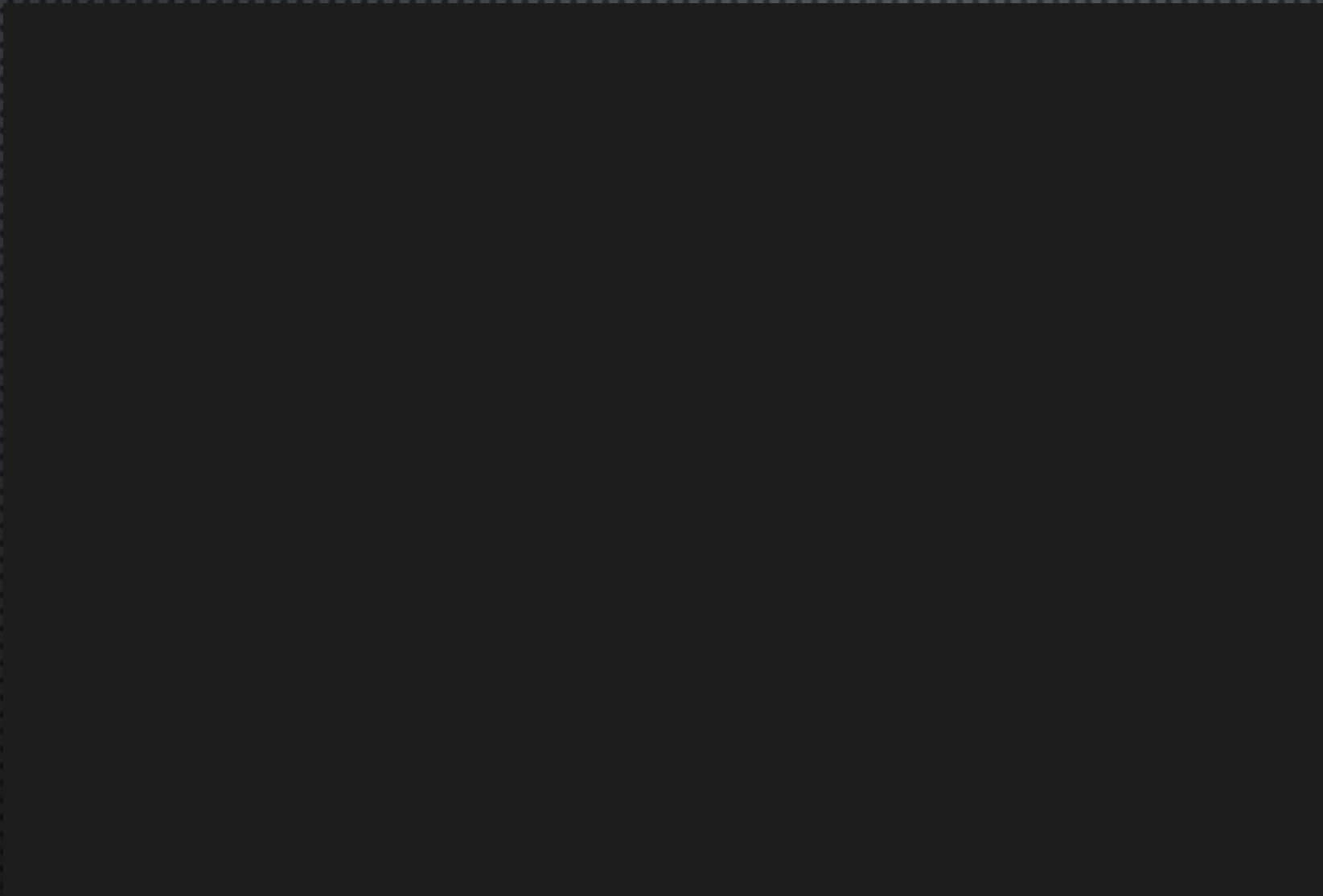
    fn file_reference(&self) -> NtfsFileReference
    where
        E: NtfsIndexEntryHasFileReference,
        { ... }
```

# WHAT'S MISSING?

- Caching
- Write support
- Features
  - Compression
  - Journaling
  - Reparse Points
  - Security Descriptors



DEMO



# DEMO

1



# Thank you for your attention!



[github.com/ColinFinck/ntfs](https://github.com/ColinFinck/ntfs)



[colin@reactos.org](mailto:colin@reactos.org)



[ColinFinck](https://twitter.com/ColinFinck)

Shoutout to the Linux-NTFS Documentation at  
<https://flatcap.github.io/linux-ntfs/ntfs>