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RecordFlux: Facilitating the Verification of Communication Protocols

Tobias Reiher
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Communication Protocols
Problems

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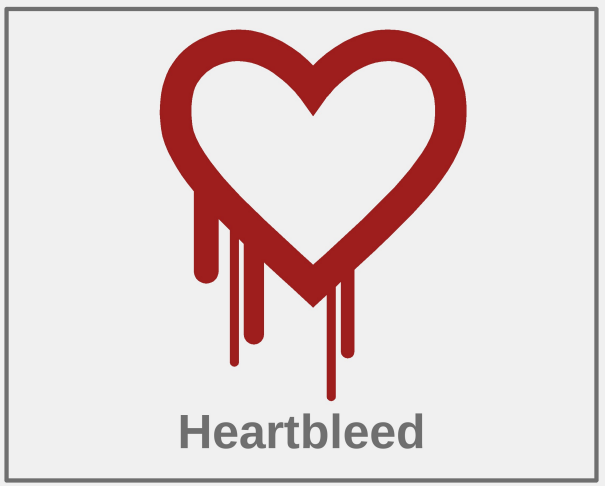

- Implementing protocols is time-consuming and error prone
- Specifications available only in English prose
- Formal protocol specification rarely exist (or are feasible to do)

Communication Protocol Verification
Solution Space

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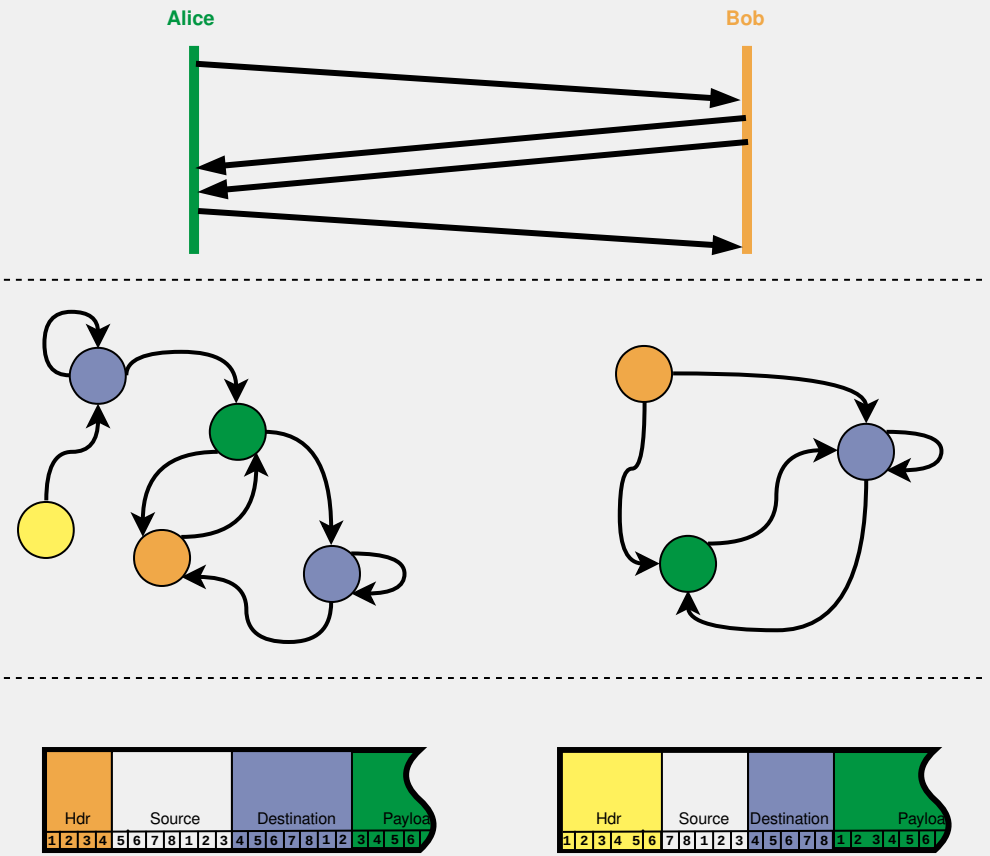
- **Security properties**
  (security protocol proofs)
- **Protocol semantics**
  (temporal logic, model checking)
- **Message formats**
  (functional correctness)
- **Absence of runtime errors**
  (program verification)



High-assurance Implementation
SPARK

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- **Programming language**
  - Imperative, object-oriented
  - Designed for error avoidance
  - Strong type system
  - Formal contracts
- **Verification toolset**
  - Data and control flow analysis
  - Dependency contracts
  - Absence of runtime errors
  - Functional correctness

- **Used in various critical and system-level projects**
  - Satellite software
  - Air Traffic Control
  - Secure workstation
  - Muen Separation Kernel (https://muen.sk)
- **More details on SPARK**
  - https://adacore.com/about-spark

High-assurance Implementation
A simple task: Calculating abs()

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```
// Calculate absolute value of x
1 int abs_value(int x)
2 {
3     if (x > 0) {
4         return x;
5     } else {
6         return -x;
7     };
8 }
```

```
// Let's try abs_value()
abs_value(-12345)      ⟹   12345
abs_value(56789)       ⟹   56789
abs_value(0)           ⟹   0
abs_value(-2147483648) ⟹   -2147483648
```

High-assurance Implementation
Calculating abs() with SPARK

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```
1 function Abs_Value (X : Integer) return Integer is
2 begin
3    if X > 0 then
4       return X;
5    else
6       return -X;
7    end if;
8 end Abs_Value;
```

```
Proving...
Phase 1 of 2: generation of Global contracts ...
Phase 2 of 2: flow analysis and proof ...
abs_value.adb:6:6: medium: overflow check might fail (e.g. when X = Integer'First) [possible explanation:
subprogram at line 1 should mention X in a precondition]
```

High-assurance Implementation
Calculating abs() with SPARK

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```
1 function Abs_Value (X : Integer) return Integer
2   with
3     Pre => X /= Integer'First;
```

```
Proving...
Phase 1 of 2: generation of Global contracts ...
Phase 2 of 2: flow analysis and proof ...
```

Communication Protocol Verification
RecordFlux

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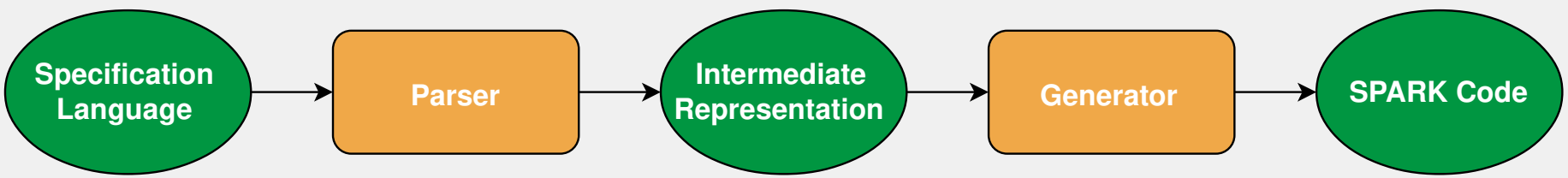
- **Objective**
  - Dissection, generation and verification of communication protocols
- **Architecture**



RecordFlux
Specification Language

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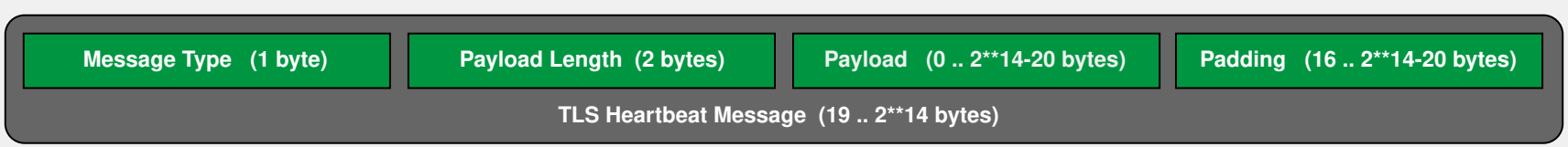
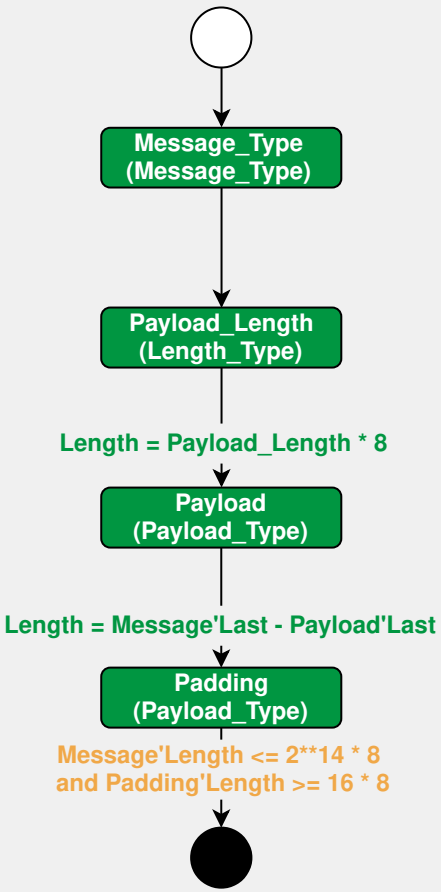
- **Type for messages**
  - Message (message)
- **Types for fields**
  - Enumeration
  - Integer (range)
  - Composite (Payload_Type)
- **Modularization**
  - Package (package)

```
package TLS_Heartbeat is
   type Message_Type is (HEARTBEAT_REQUEST  => 1,
                         HEARTBEAT_RESPONSE => 2)
      with Size => 8;
   type Length_Type is range 0 .. 2**14 - 20
      with Size => 16;
   type Heartbeat_Message is
      message
         Message_Type   : Message_Type;
         Payload_Length : Length_Type;
         Payload        : Payload_Type;
         Padding        : Payload_Type;
      end message;
end TLS_Heartbeat;
```

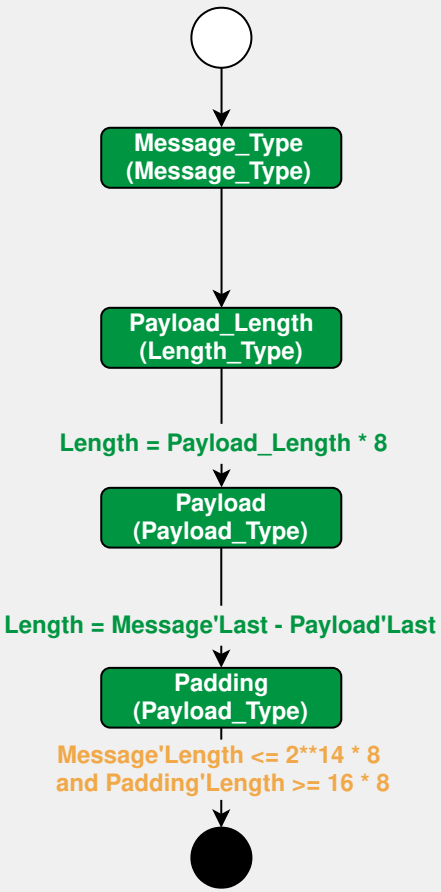


RecordFlux
Specification Language



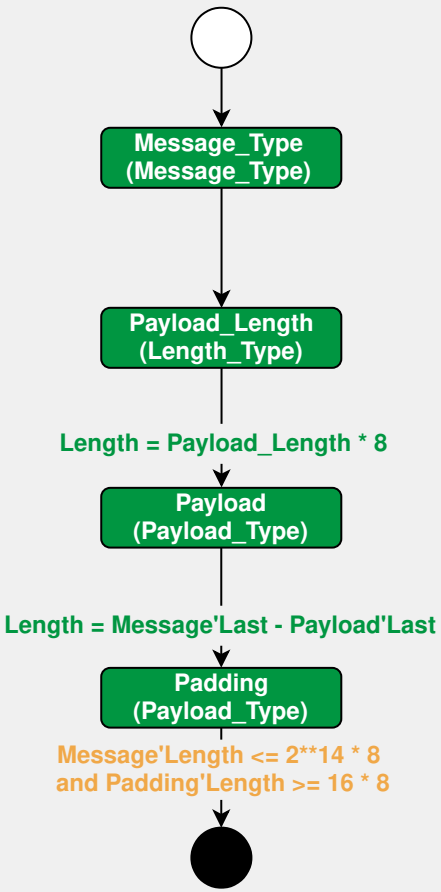

```
package TLS_Heartbeat is

   type Message_Type is (HEARTBEAT_REQUEST => 1, HEARTBEAT_RESPONSE => 2)
      with Size => 8;

   type Length_Type is range 0 .. 2**14 - 20 with Size => 16;

   type Heartbeat_Message is
      message
         Message_Type : Message_Type;
         Payload_Length : Length_Type
            then Payload
               with Length = Payload_Length * 8;
         Payload : Payload_Type
            then Padding
               with Length = Message'Last - Payload'Last;
         Padding : Payload_Type
            then null
               if Message'Length <= 2**14 * 8 and Padding'Length >= 16 * 8;
      end message;

end TLS_Heartbeat;
```

RecordFlux
Code Generation




```
[…]

function Is_Contained (Buffer : Bytes) return Boolean
  with Ghost, Import;

procedure Label (Buffer : Bytes)
  with Post => Is_Contained (Buffer);

function Valid_Message_Type (Buffer : Bytes) return Boolean
  with Pre => Is_Contained (Buffer);

function Get_Message_Type (Buffer : Bytes) return Message_Type
  with Pre => (Is_Contained (Buffer) and then Valid_Message_Type (Buffer));

function Valid_Payload (Buffer : Bytes) return Boolean
  with Pre => Is_Contained (Buffer);

procedure Get_Payload (Buffer : Bytes; First : out Natural; Last : out Natural)
  with Pre => (Is_Contained (Buffer) and then Valid_Payload (Buffer)),
       Post => (First = Get_Payload_First (Buffer) and then
                Last = Get_Payload_Last (Buffer));

function Is_Valid (Buffer : Bytes) return Boolean
  with Pre => Is_Contained (Buffer);

[…]
```

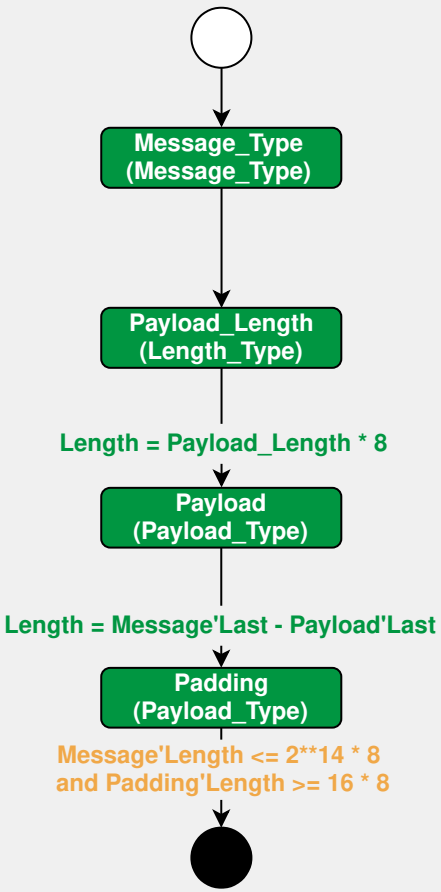
RecordFlux
Using the Generated Code




```
with TLS.Heartbeat_Message; use TLS.Heartbeat_Message;

procedure Main is
   Buffer : Bytes := Read;
   Tag    : Message_Type;
   First  : Natural;
   Last   : Natural;
begin

   Label (Buffer);



   Tag := Get_Message_Type (Buffer);

   Get_Payload (Buffer, First, Last);



end Main;
```

```
Proving...
Phase 1 of 2: generation of Global contracts ...
Phase 2 of 2: flow analysis and proof ...
tls-test.adb:10:6: medium: precondition might fail
tls-test.adb:12:6: medium: precondition might fail
```

RecordFlux
Using the Generated Code

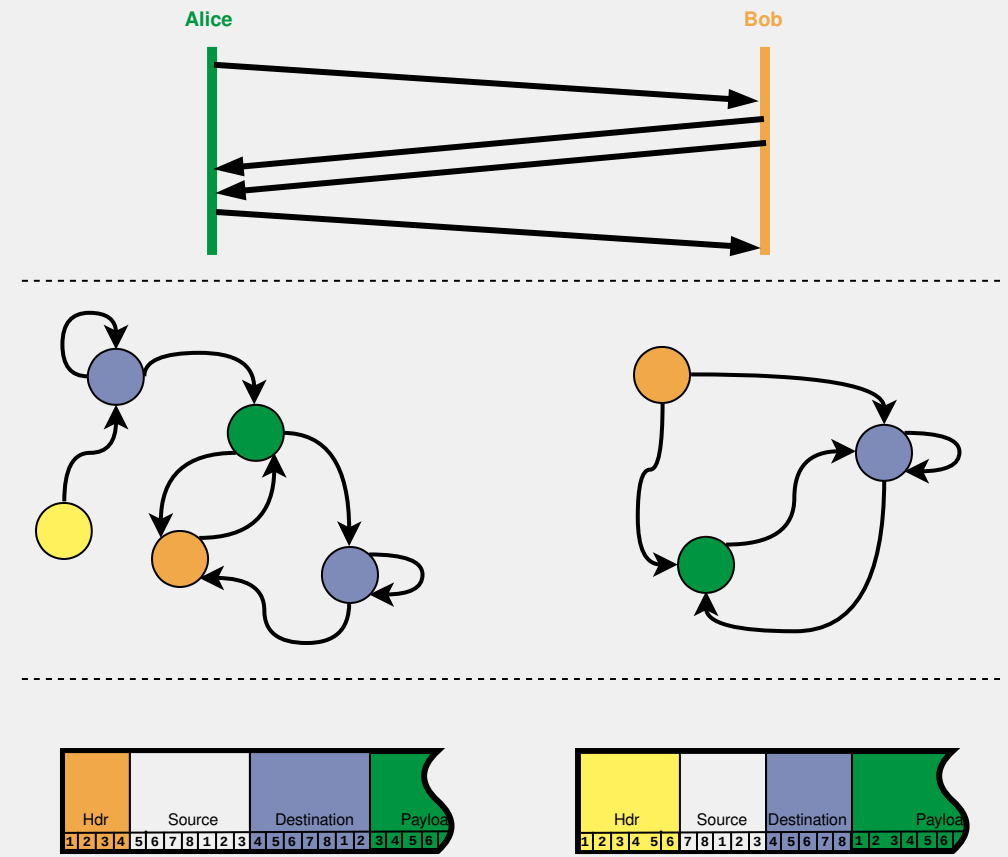



```
with TLS.Heartbeat_Message; use TLS.Heartbeat_Message;

procedure Main is
   Buffer : Bytes := Read;
   Tag    : Message_Type;
   First  : Natural;
   Last   : Natural;
begin

   Label (Buffer);

   if Is_Valid (Buffer) then

      Tag := Get_Message_Type (Buffer);

      Get_Payload (Buffer, First, Last);

   end if;

end Main;
```

```
Proving...
Phase 1 of 2: generation of Global contracts ...
Phase 2 of 2: flow analysis and proof ...
```

RecordFlux
Current State

- **Security properties**
  (security protocol proofs)
  - *Future work*
- **Protocol semantics**
  (temporal logic, model checking)
  - *Future RecordFlux version*
- **Message formats**
  (functional correctness)
  - *Addressed by RecordFlux*
- **Absence of runtime errors**
  (program verification)
  - *Addressed by SPARK*



RecordFlux
Application: GreenTLS

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- Component-based high-assurance implementation of TLS 1.3
- Started this year, partially funded by European Union and state of Saxony
- Critical components in SPARK using RecordFlux
- Genode OS Framework as a base platform, but potentially others
- Challenges
  - How to separate architecture (without breaking it!)?
  - How can security be proven?
  - Performance vs. side channel avoidance?
  - ...
- Source available on GitHub: https://github.com/Componolit/GreenTLS

Europäische Union
Europa fördert Sachsen.
ESF
Europäischer Sozialfonds
SACHSEN
Diese Maßnahme wird mitfinanziert durch Steuermittel auf Grundlage des von den Abgeordneten des Sächsischen Landtags beschlossenen Haushaltes.

RecordFlux
Conclusion

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- **Current state**
  - Specification language powerful enough to specify real-world binary protocols: Ethernet, IPv4, UDP, and TLS 1.3 (in progress)
  - Generation of SPARK 2014 code:
    Absence of runtime errors and correctness of message formats
- **Next steps**
  - Message generation
  - More protocols (e.g., USB)
  - Non-TLV message schemes
- **Source code**
  - Available on GitHub: https://github.com/Componolit/RecordFlux

Questions?

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Tobias Reiher
reiher@componolit.com

@Componolit · componolit.com · github.com/Componolit