Componolit
Secure Systems Engineering

Combining program verification with component-based architectures

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About Componolit

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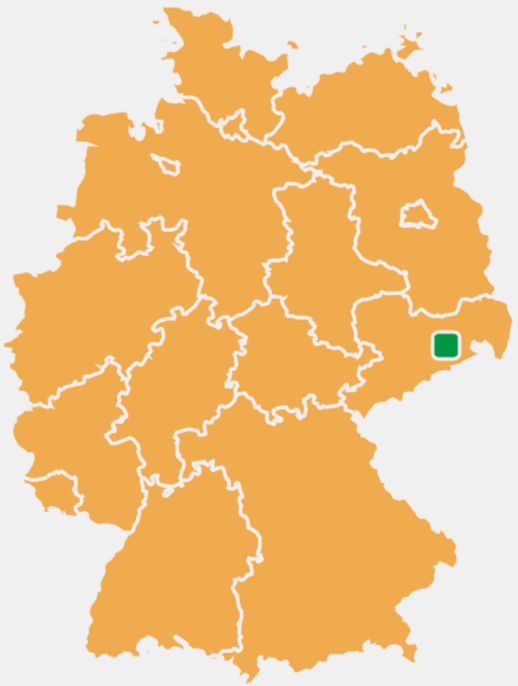
- **Topic:** Secure component-based systems
- **Focus:** Mobile devices, industrial security
- **Principles**
  - Free software
  - Open development
  - Security-by-design



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What happens when we use what's best?

What's Best?
Mid-90ies: DOS+Pascal

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```
program WriteName;
var
  i    : Integer;          {variable to be used for looping}
  Name : String;           {declares the variable Name as a string}
begin
  Write('Please tell me your name: ');
  ReadLn(Name);            {Return string entered by the user}
  for i := 1 to 100 do
  begin
    WriteLn('Hello ', Name)
  end;
 readln;
end.
```

What's Best?
End of 90ies: Linux+C

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```
if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
  goto fail;
  goto fail;
... other checks ...
fail:
  ... buffer frees (cleanups) ...
  return err;
```

What's Best?
Mid 2000s: Linux/FreeBSD/NetBSD+Ada

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```
type Day_type   is range    1 ..   31;
type Month_type is range    1 ..   12;
type Year_type  is range 1800 .. 2100;
type Hours is mod 24;
type Weekday is (Monday, Tuesday, Wednesday,
                 Thursday, Friday, Saturday, Sunday);
type Date is
   record
     Day   : Day_type;
     Month : Month_type;
     Year  : Year_type;
   end record;
```

What's Best?
Today and in the Future

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That's what this talk is about.

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“Use what’s best”

⇒

“Trustworthy systems”

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¬ “Use what’s best”

⇒

???

What's Best?
Our answer (so far) – Outline

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- **Problem**
  - Unsafe programming languages
  - Monolithic systems
- **Solution**
  - Component-based systems
  - Program verification
- **Future**
  - Verification of high-level models
  - Protocol verification

Problem
Unsafe Programming Languages

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- Stragefright (July 2015)
  - Billions of devices affected
  - Remote code execution, privilege escalation
  - As easy as sending video/image
- Problem not solved since
  - > 350 bugs (critical/high)
    - Integer overflows
    - Integer underflows
    - Buffer overflows
    - Heap overflows

Stagefright malware is back! 'Worst Android bug in history' returns for a third time and could infect a BILLION phones

- **Stagefright bug lets attackers take control of older Android handsets**
- **Notorious bug is back for a third time, security research firm claims**
- **Israel-based NorthBit security researchers seem to show the hack in action**
- **It only affects handsets running software older than Android 4.0 and people are being told to upgrade, and install anti-malware apps**

By SARAH GRIFFITHS FOR MAILONLINE
PUBLISHED: 10:59 BST, 21 March 2016 | **UPDATED:** 23:17 BST, 21 March 2016

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Just as stage fright can plague an actor repeatedly, a notorious Android bug that goes by the same name, is back for a third time.

The 'worst Android vulnerability in the mobile OS history' with the potential to infect one billion handsets, allows cybercriminals to hack an Android smartphone in less than 10 seconds.

The newest version of Stagefright, also referred to as Metaphor, tricks a user into visiting a hacker's web page, containing a malicious multimedia file that when

Problem
Monolithic Systems

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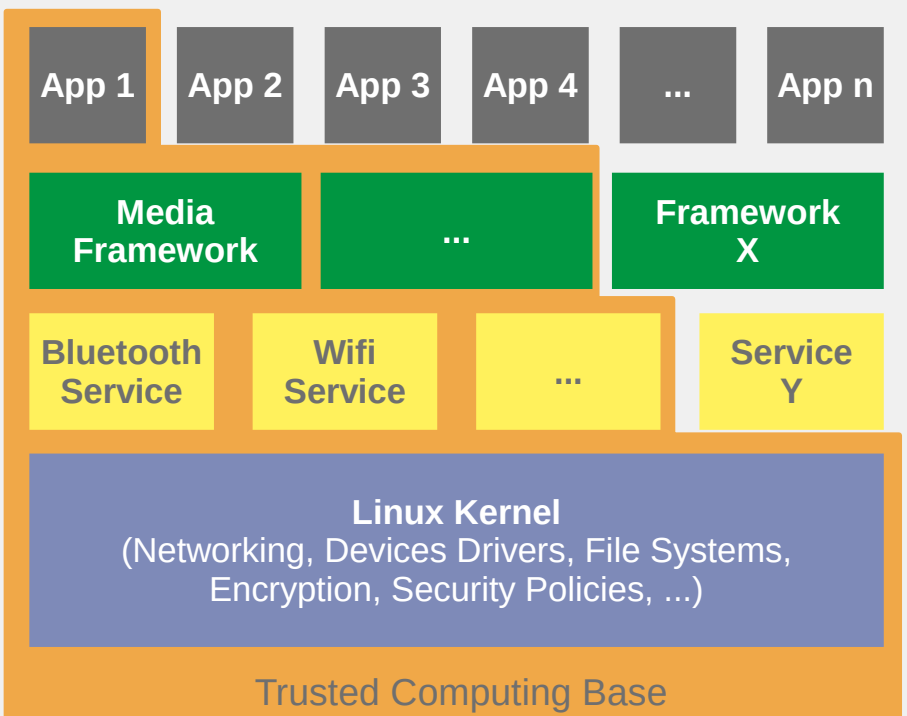
- Typical System Architecture



- **Most systems monolithic today**
  - Complex features
  - Large, shared services
  - Weak isolation
- **Consequences**
  - Large Trusted Computing Base
  - High error probability
  - Unrestricted error propagation

Solution
Our Constraints

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- Minimal Trusted Computing Base
- System/low-level programming
- Low overhead

Solution
The Genode OS Framework*

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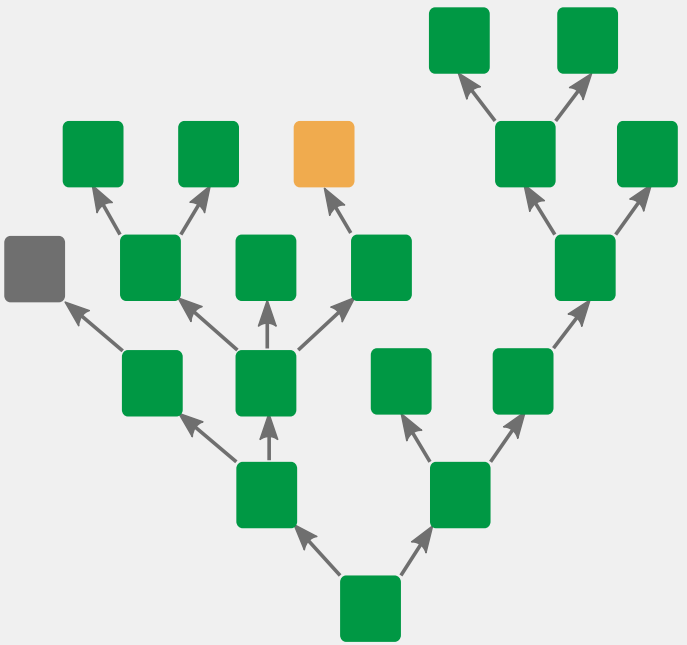
- **Recursive system structure**
  - Root: Microkernel
  - Parent: Responsibility + control
  - Isolation is default
  - Strict communication policy
- **Everything is a user-process**
  - Application
  - File systems
  - Drivers, Network stacks

- **Hierarchical System Architecture**



*) https://genode.org

Solution
Minimal Trusted Computing Base

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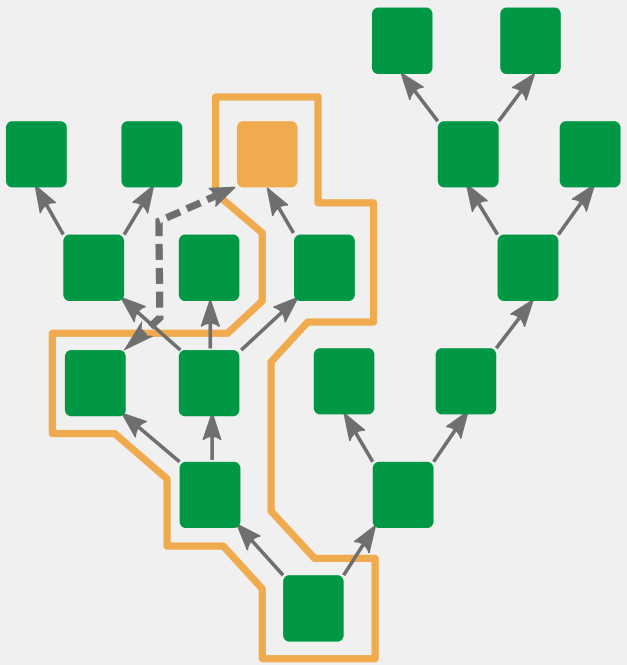
- **Trusted Computing Base**
  - Software required for security
  - Parents in tree
  - Services used
- **TCB reduction**
  - Application-specific
  - Example: File system

- **Per-application TCB**



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Does that mean we have to reimplement everything?

Strategy #1: Policy Objects

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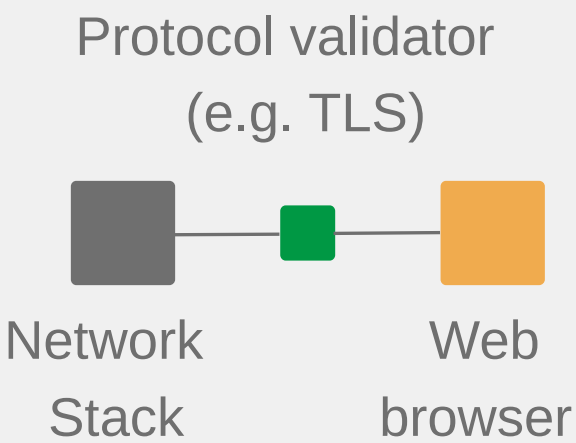
- Can’t reimplement everything
- **Solution: software reuse**
  - Untrusted software (gray)
  - Policy object (green)
  - Client software (orange)
- **Policy object**
  - Establishes assumptions of client
  - Sanitizes
  - Enforces additional policies

- **Policy objects**



Architecture for Trustworthy Systems
Strategy #2: Trusted Wrappers

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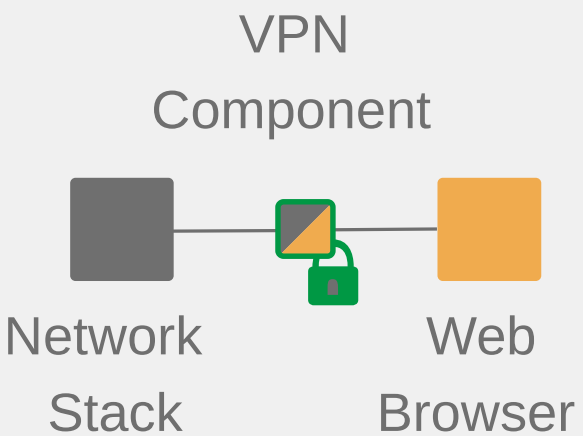
- Untrusted software (gray)
  - E.g. disk, file system, cloud
- Trusted wrapper
  - Mandatory encryption
- Client software (orange)
  - No direct interaction with untrusted components
  - Minimal attack surface

- **Trusted wrapper**



Strategy #3: Transient components

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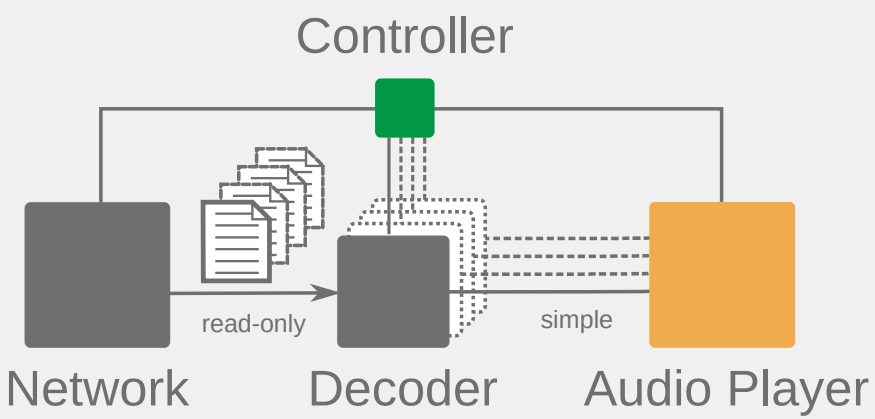
- **Untrusted software**
  - E.g. Media decoder
  - No chance to get this right!
- **Transient component**
  - Temporarily instantiate untrusted software for single file/stream
  - Expose only simple interfaces (e.g. PCM audio)
  - Cleanup on completion

- **Transient component**



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But, what if trusted components fail?

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

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```
// Calculate absolute 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
At a glance: SPARK*

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- **Language + verification toolset**
  - Imperative, object-oriented
  - Designed for error avoidance
  - Strong type system
  - Formal contracts

- **Depth of verification is flexible**
  - Data and control flow analysis
  - Dependency contracts
  - Absence of runtime errors
  - Functional correctness

*) http://spark-2014.org

High-assurance Implementation
SPARK benefits

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- **Well-suited for system-level development**
  - Compiled using GCC (via GNAT Ada frontend)
  - Supports runtime-free mode (via profiles)
  - Integration of full Ada and bindings to C
- **Used in various critical and system-level projects**
  - Muen Separation Kernel (https://muen.sk)
  - Satellite software, air traffic control, secure workstation

High-assurance Implementation
Our previous example

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```
 1 function Abs_Value (X : Integer) return Integer
 2 with
 3    -- Uncomment the following line to prove
 4    -- Pre  => X /= Integer'First,
 5    Post => Abs_Value'Result = abs (X)
 6 is
 7 begin
 8    if X > 0 then
 9       return X;
10    else
11       return -X;
12    end if;
13 end Abs_Value;
```

```
Proving...
Phase 1 of 2: generation of Global contracts ...
Phase 2 of 2: flow analysis and proof ...
abs_value.adb:11:14: medium: overflow check might fail (e.g. when Abs_Value'Result = 0 and X = -2147483648)
One error.
```

High-assurance Implementation
Bitwise swap using XOR

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```
 1 with Interfaces; use Interfaces;
 2
 3 procedure Bitwise_Swap (X, Y : in out Unsigned_32) with
 4   Post => X = Y'Old and Y = X'Old
 5 is
 6 begin
 7   X := X xor Y;
 8   Y := X xor Y;
 9 -- Uncomment the following line to prove
10 -- X := X xor Y;
11 end Bitwise_Swap;
```

```
Proving...
Phase 1 of 2: generation of Global contracts ...
Phase 2 of 2: flow analysis and proof ...
bitwise_swap.adb:4:11: medium: postcondition might fail,
   cannot prove X = Y'old (e.g. when X = 0 and Y'Old = 4294967295)
One error.
```

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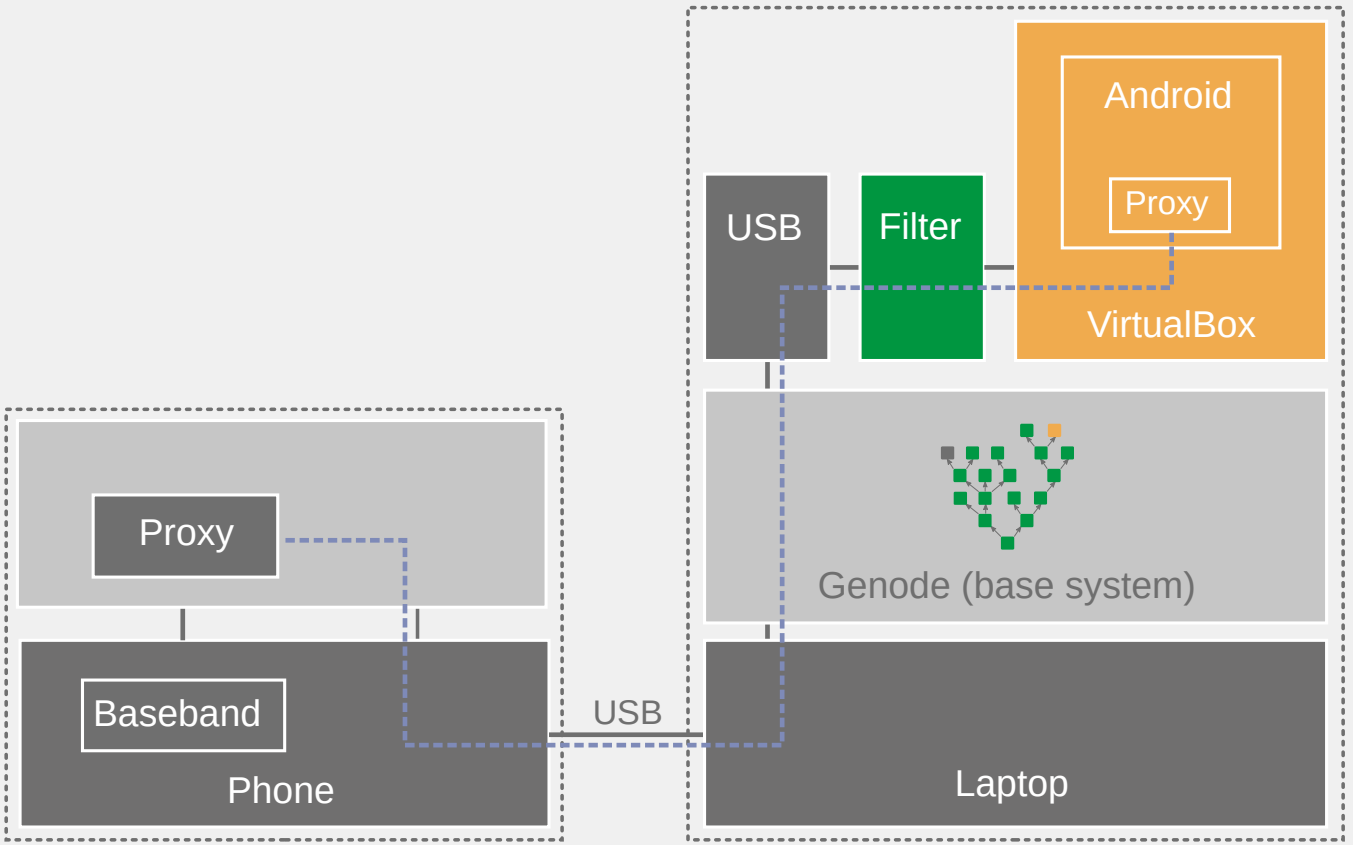
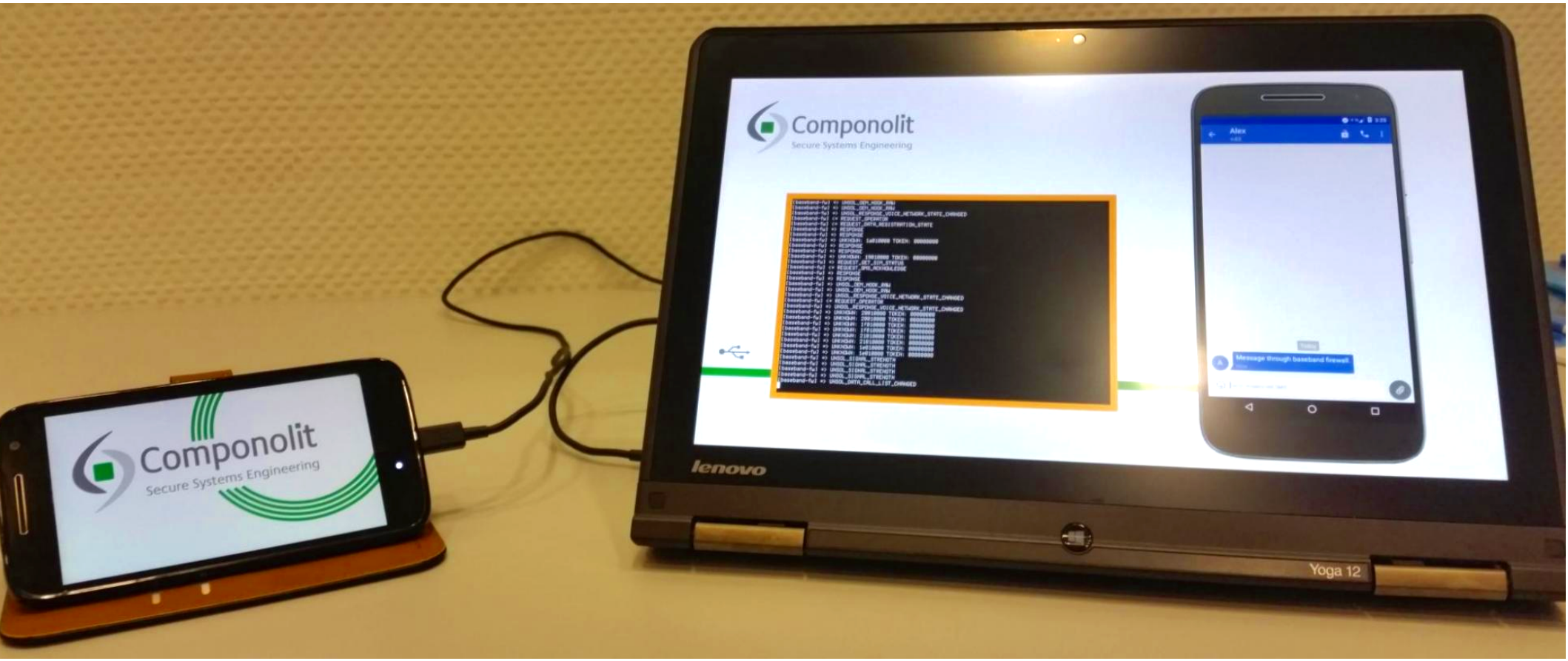
Let’s put it together.

Componolit Platform
Baseband firewall – Architecture



Componolit Platform
Baseband firewall – Implementation



What's Best?
Future: More Verification!

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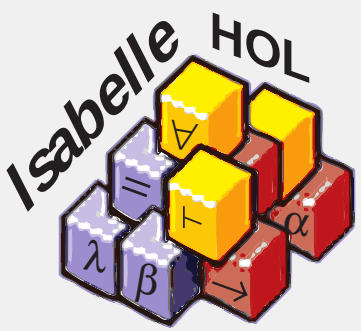
- **Interactive theorem proving**
  - Functional specification in Isabelle/HOL
  - Prove correspondence with SPARK program



- **Protocol verification**
  - See ourselves implementing communication protocols…
  - ...over and over again
- **Goal**
  - Closed specification of communication protocols
  - Verification of protocol properties using temporal logic
  - Generation of code

Interested in ideas!

Questions?

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Stagefright
Bugs rated critical/high since 2015

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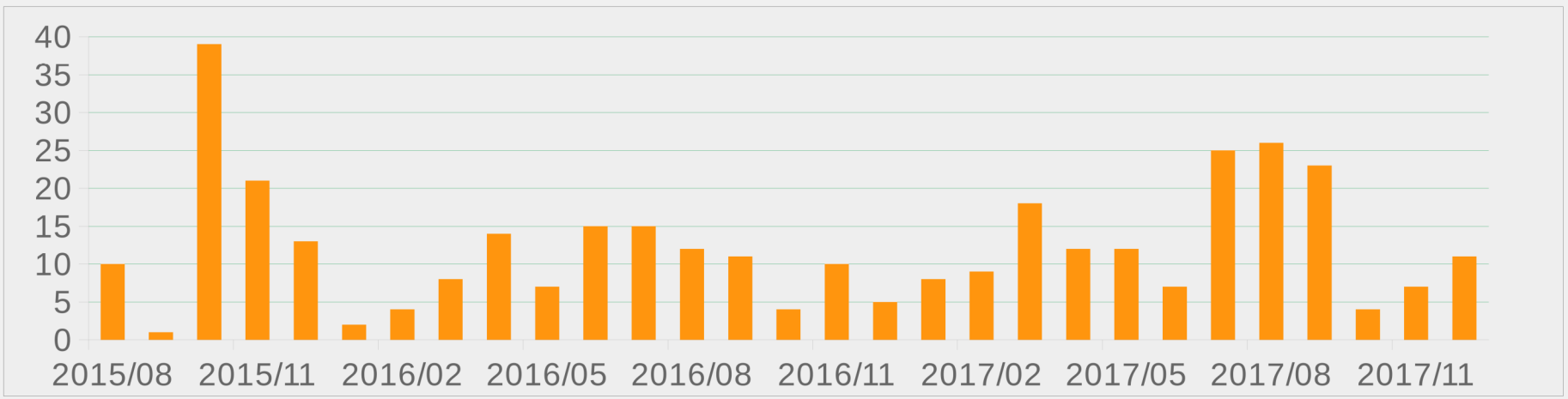

Media-related Android vulnerabilities (Critical/high, based on https://source.android.com/security/bulletin/)