Native Client: A Sandbox for portable, untrusted x86 Native Code

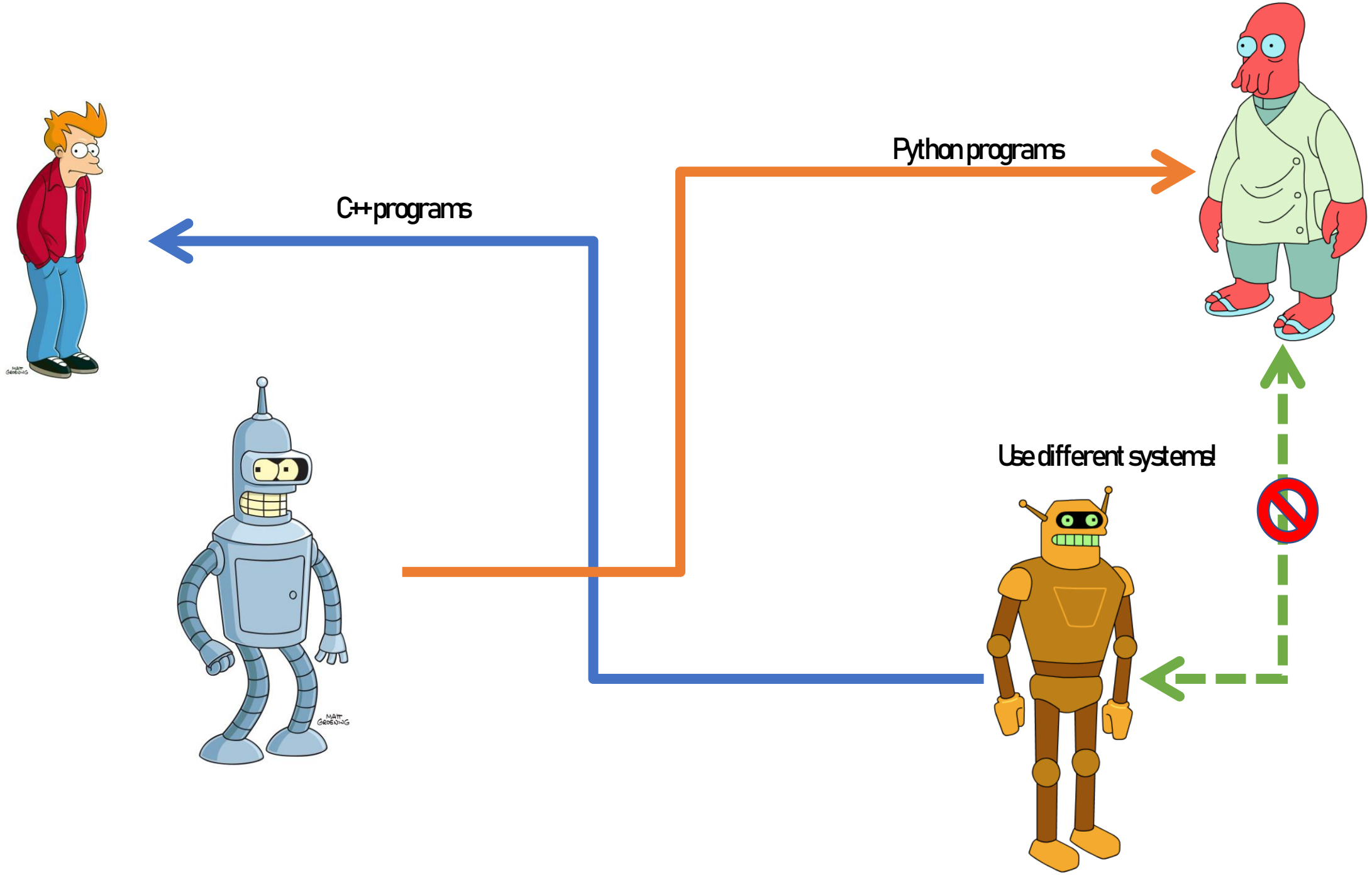
B. Yee, D. Sehr, G. Dardyk, J.B. Chen, R. Muth, T. Ormandy, S. Okasaka, N. Narula, and N. Fullagar

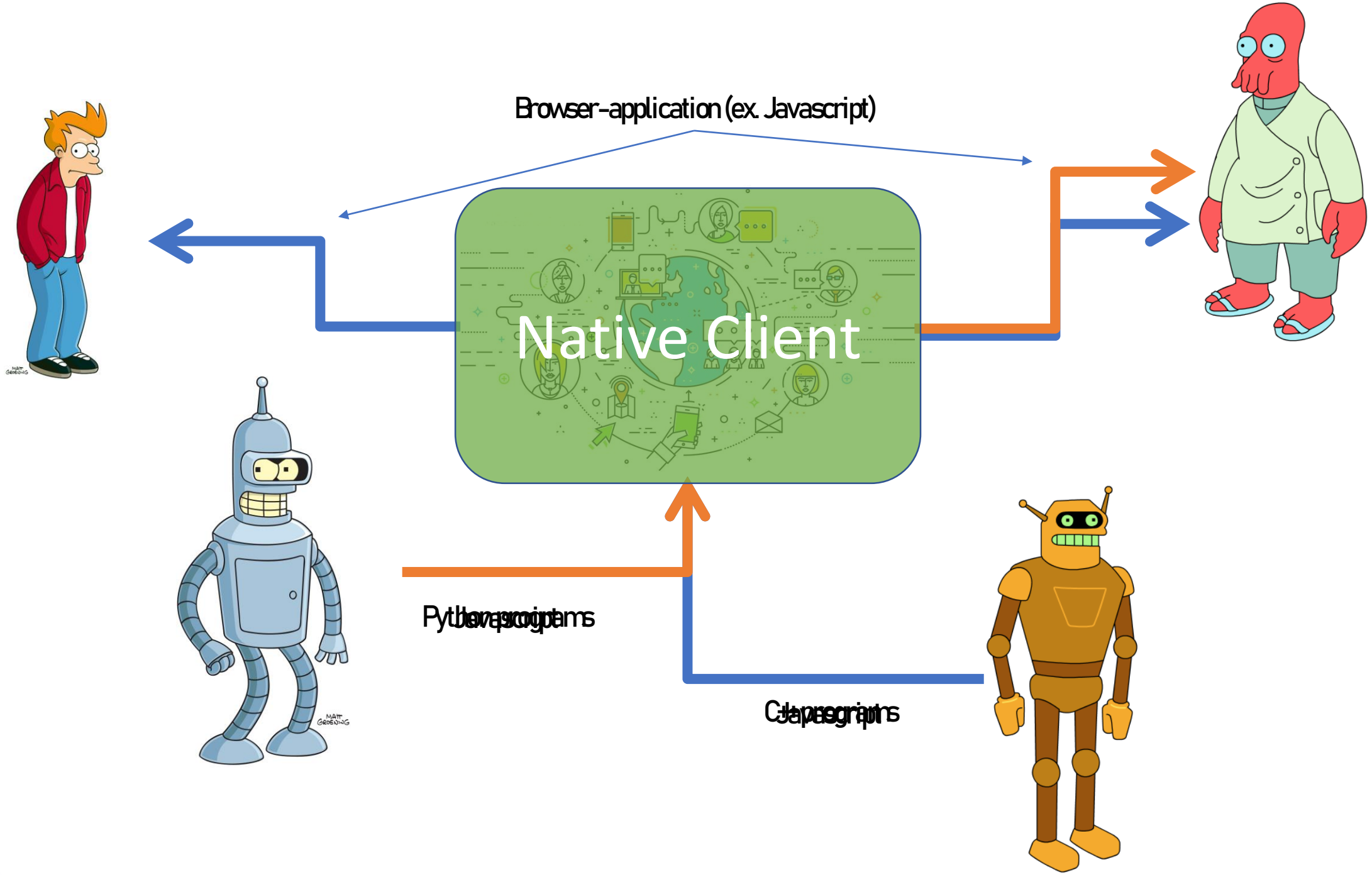
Google Inc.

Chinmay Nirkhe

nirkhe@cs.berkeley.edu

Berkeley
UNIVERSITY OF CALIFORNIA


Python programs
C++programs
Use different systems!

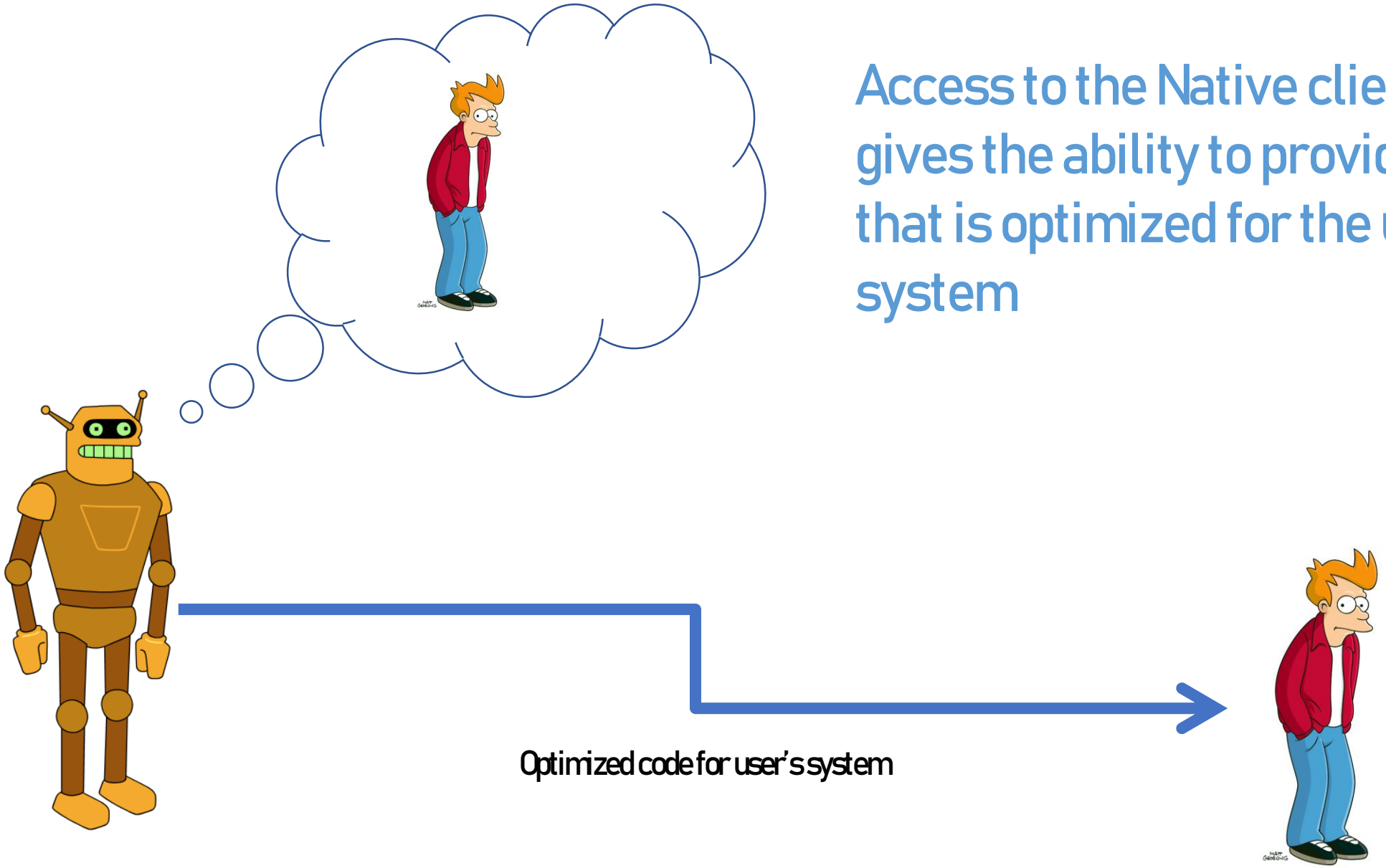

Browser-application (ex. Javascript)
Native Client
Python programs
Java programs
C++ programs

Secure execution of native code in the web browser

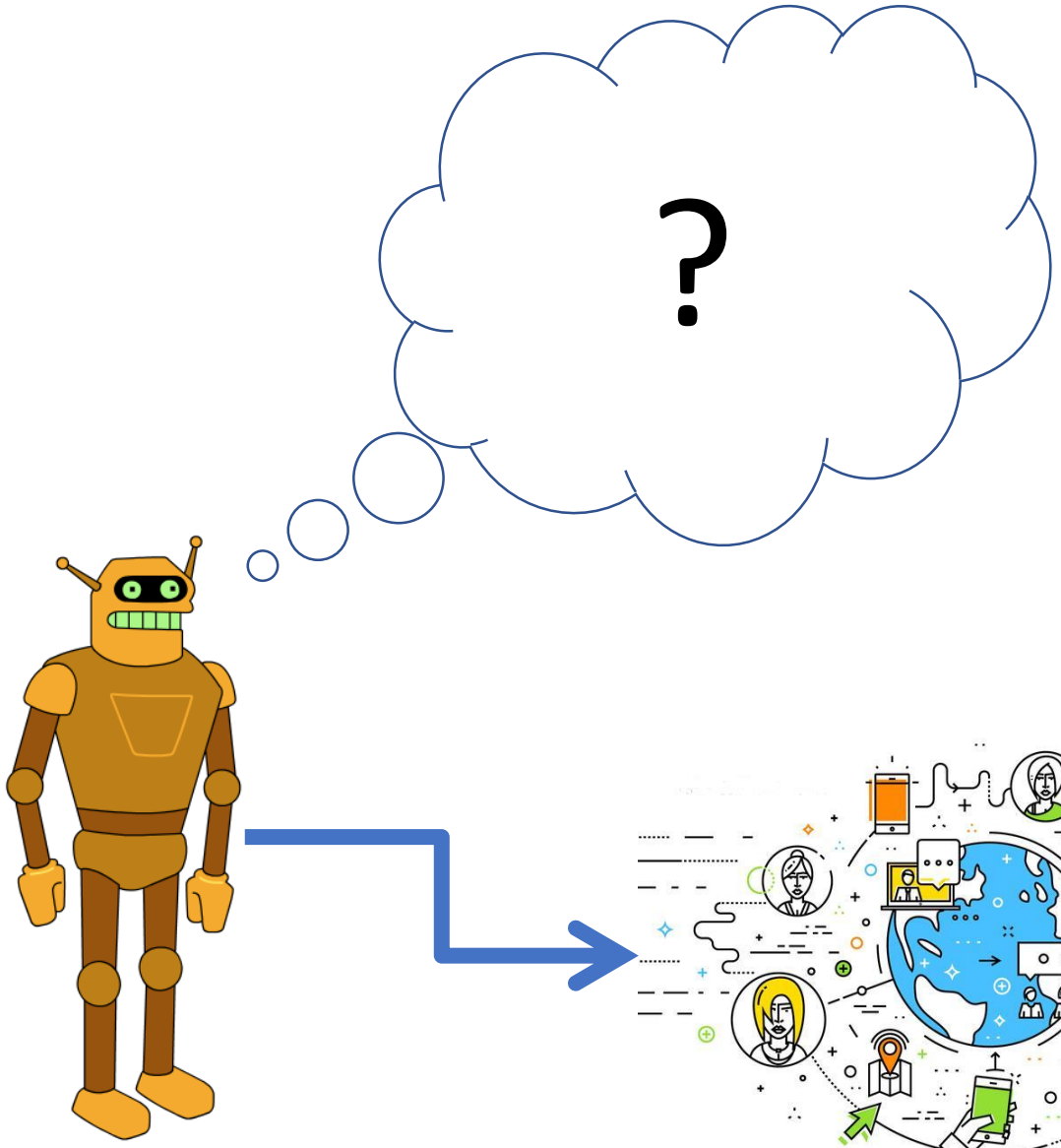
- Existing software components
- Legacy desktop applications
- Heavy computation in enterprise applications
- Multimedia applications
- Games
- Any application that requires acceleration

Secure execution of native code in the web browser

Access to the Native client, gives the ability to provide code that is optimized for the user's system

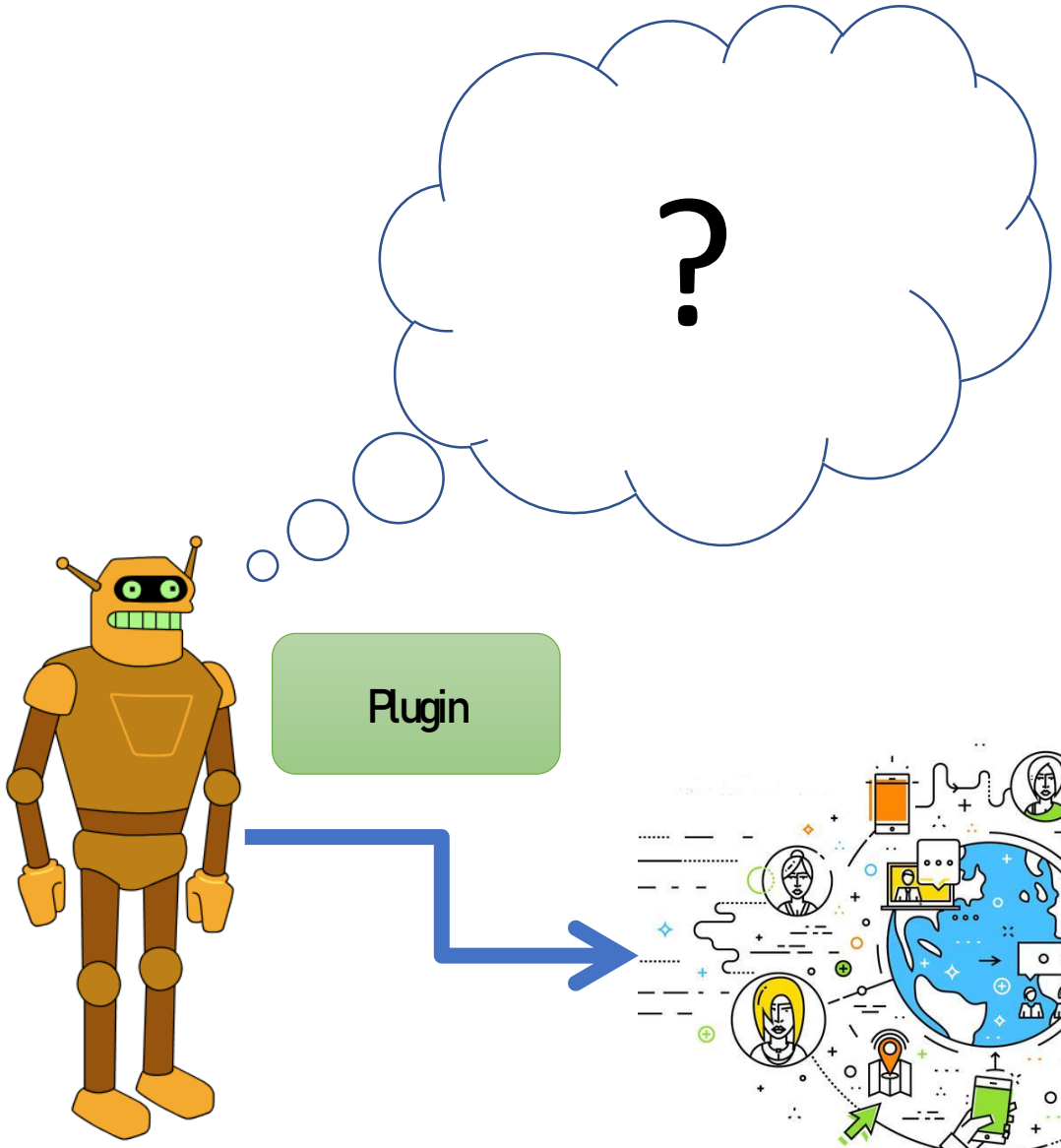


Generic browser-based applications cannot access the clients full computational potential without hindering security.



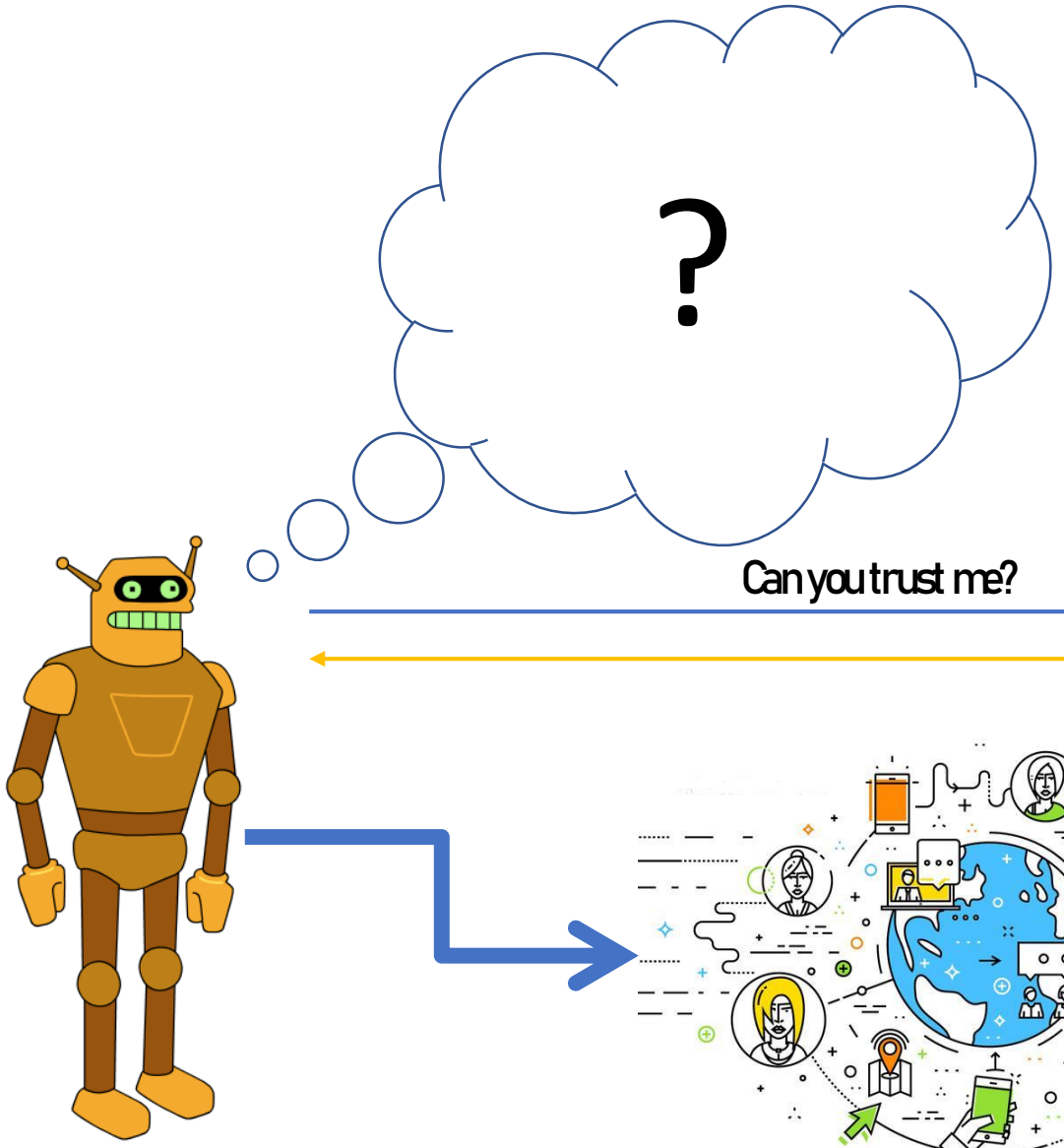
Oblivious of the specifics of the client

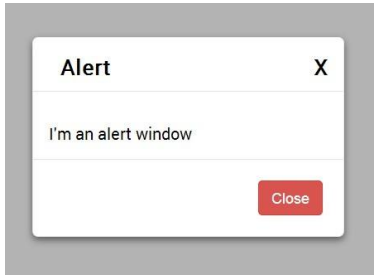
Generic browser-based applications cannot access the clients full computational potential without hindering security.



Oblivious of the specifics of the client

Generic browser-based applications cannot access the clients full computational potential without hindering security.



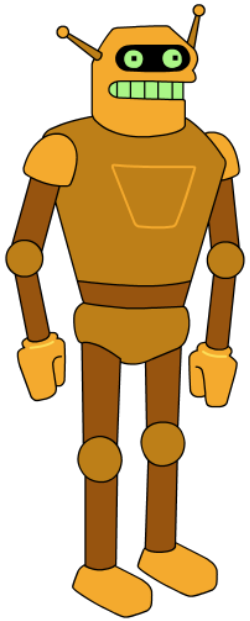


Oblivious of the specifics of the client

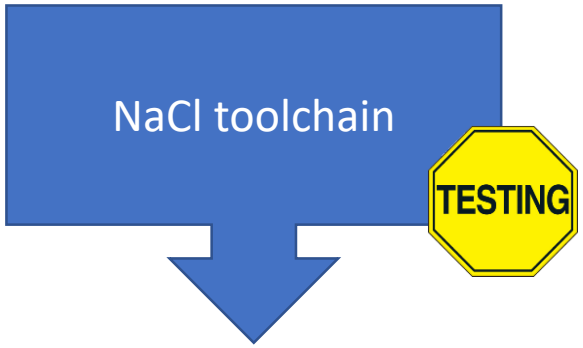
The Challenge

Provide browser-based applications the computational performance of native applications without compromising safety.

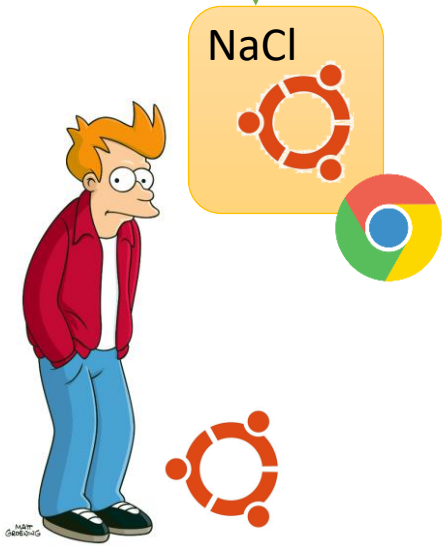
What happens in the Sandbox, stays in the Sandbox.



Some code to turn into binary



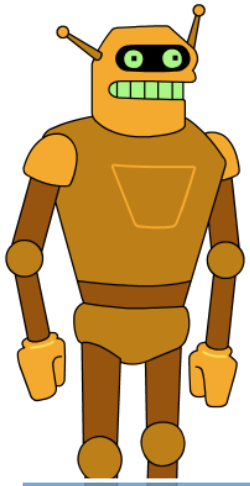
nexe executable



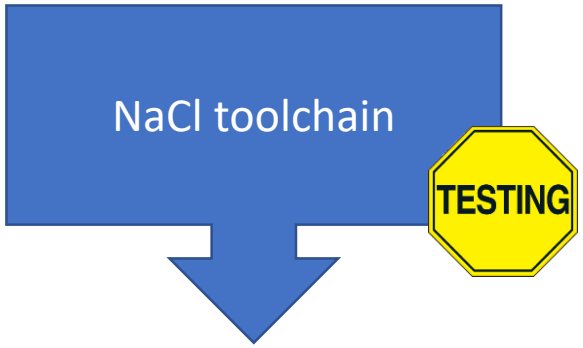
Generate Hardware Optimized Sandboxes

Test binary code for security loopholes

Run on respective clients



Some code to turn into binary



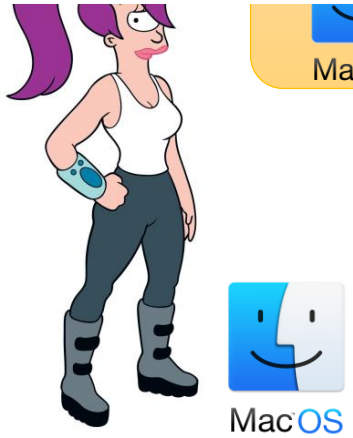
Generate Hardware Optimized Sandboxes

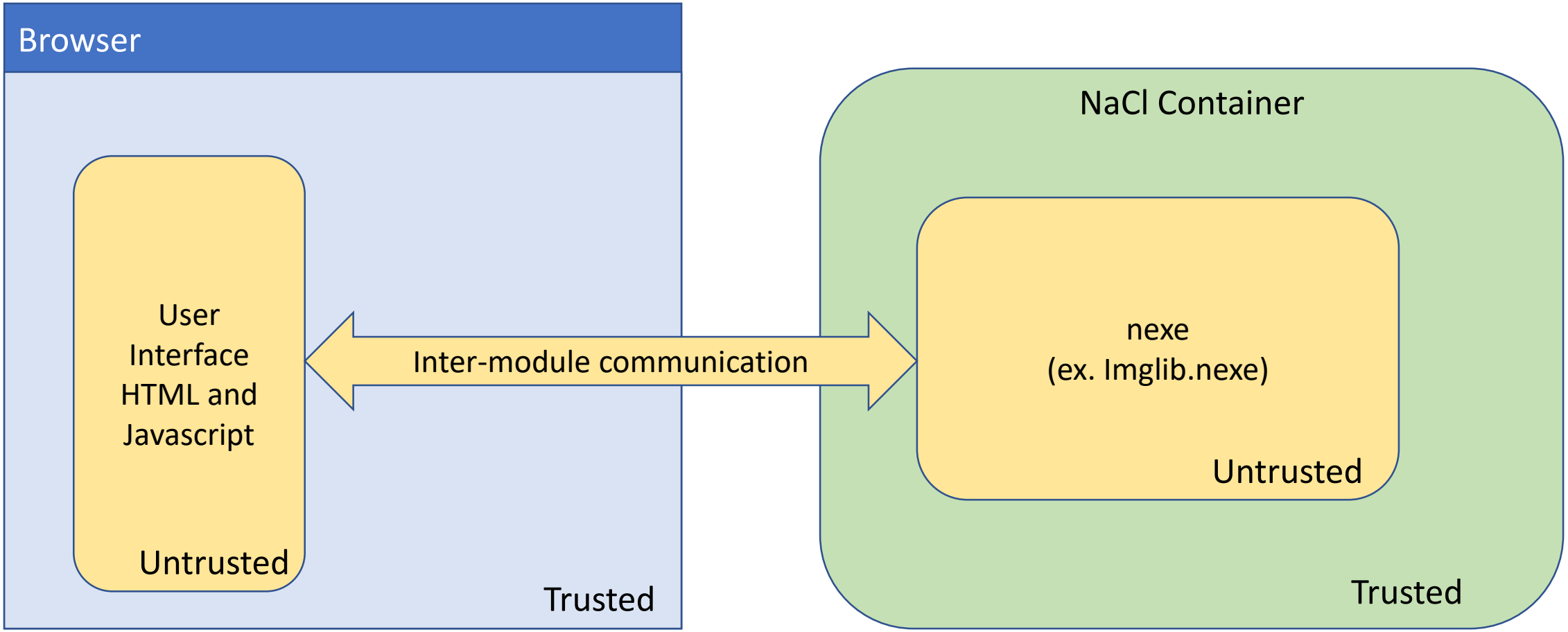
Test binary code for security loopholes

Run on respective clients

nexe executable

The onerous of developing for different systems is now on Native Client and no longer on the developer



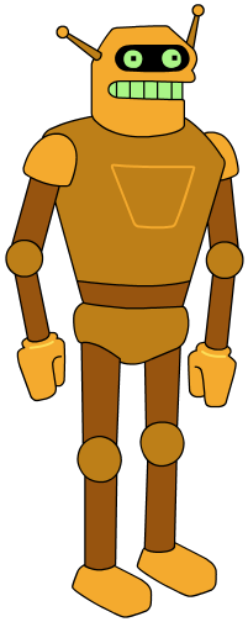

Browser
User Interface HTML and Javascript
Untrusted
Trusted
Inter-module communication
NaCl Container
nexe
(ex. Imglib.nexe)
Untrusted
Trusted

DETAILS AHEAD

STOP PAYING ATTENTION NOW IF SUMMARY WAS SUFFICIENT

IF SUMMARY WAS SUFFICIENT

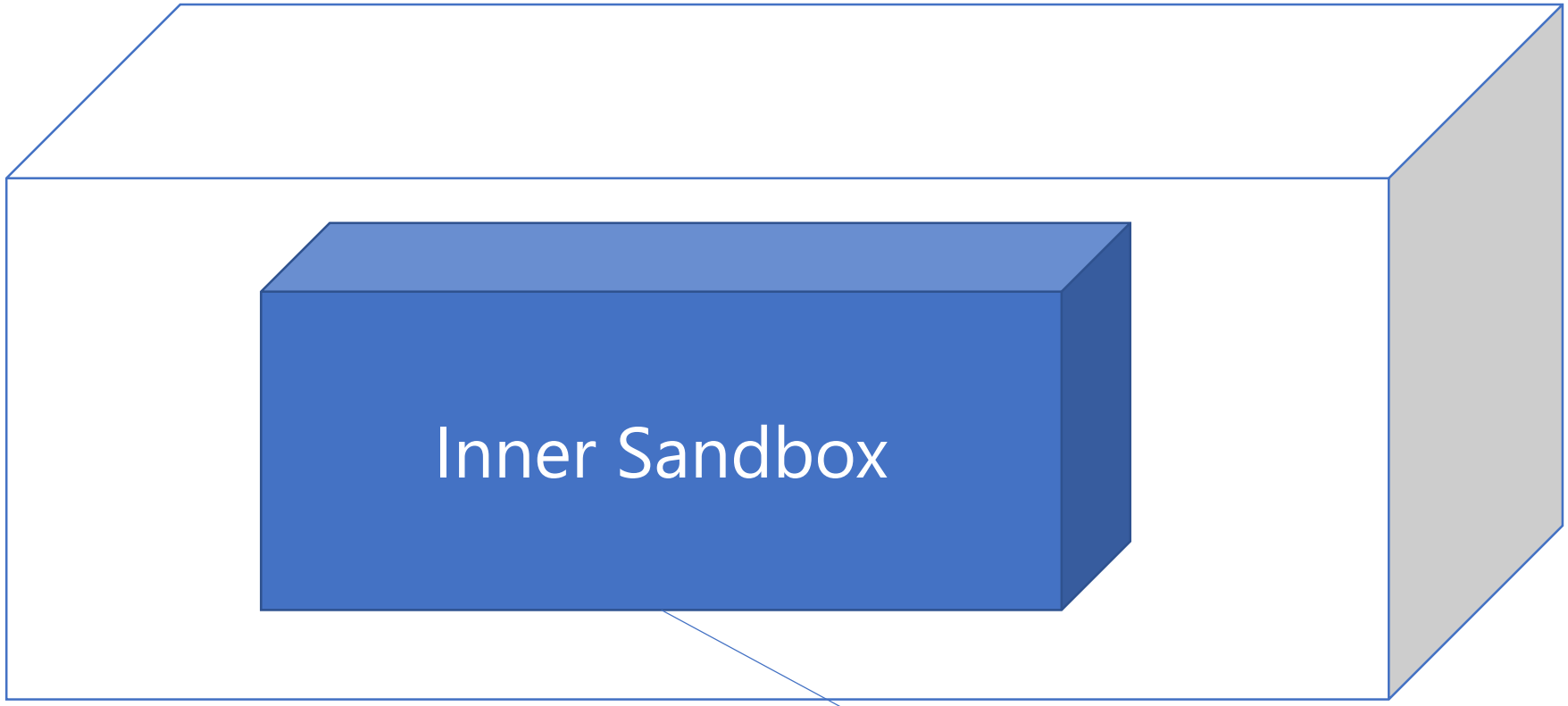
But how can I trust the binary code that the server wants to run on my client?



Don't trust me. Trust NaCl. I'm totally sandboxed!

Google claims that NaCl can handle

- Untrusted modules from any website
- Unintended side effects outside the sandbox
- Handle allocation of memory and additionally spawned threads
- Handle any race condition attacks

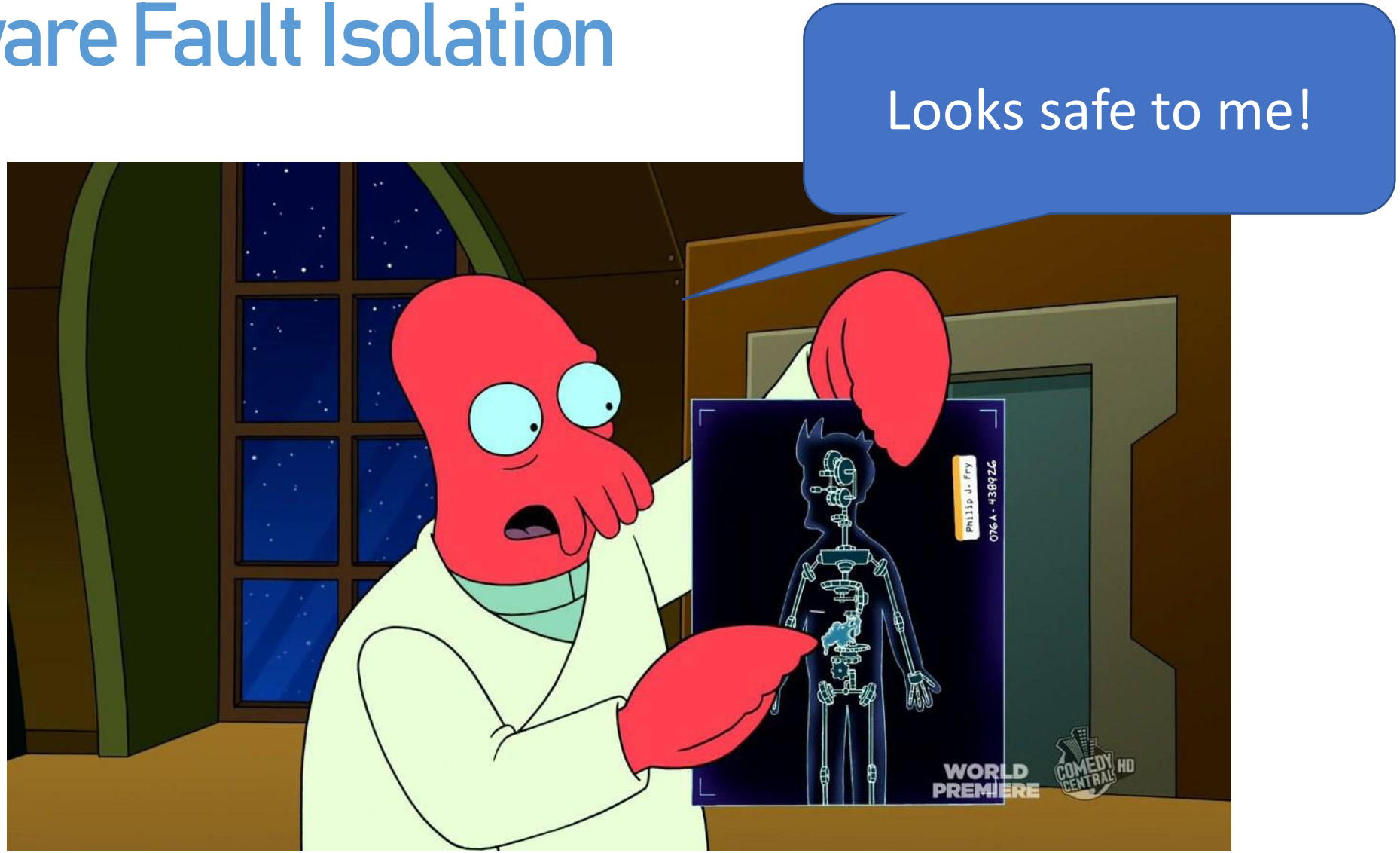


Outer Sandbox

- Handles the same security threats as standard Sandbox used by OS
- Additional level of security not strictly necessary

- Static analysis to discover security defects in x86 code
- Disallow self-modifying code and overlapping instructions
- Provide reliable disassembly

Software Fault Isolation



UNSAFE

instrumentation

memory access

jumps/returns

prohibited

system call

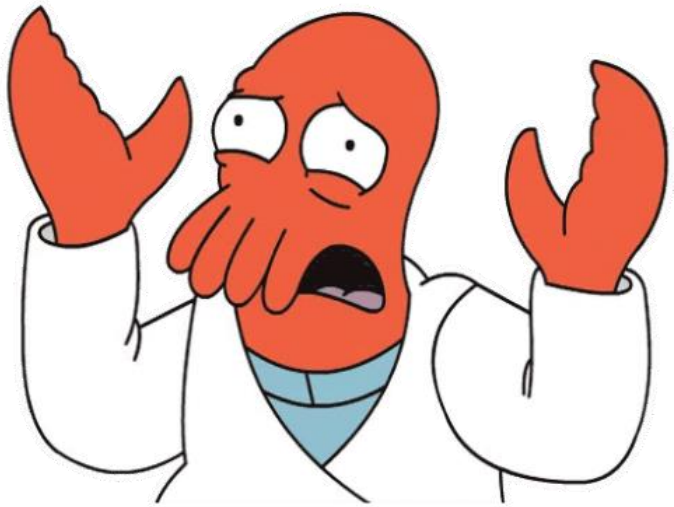
interrupts

SAFE

Moves between registers (in sandbox)

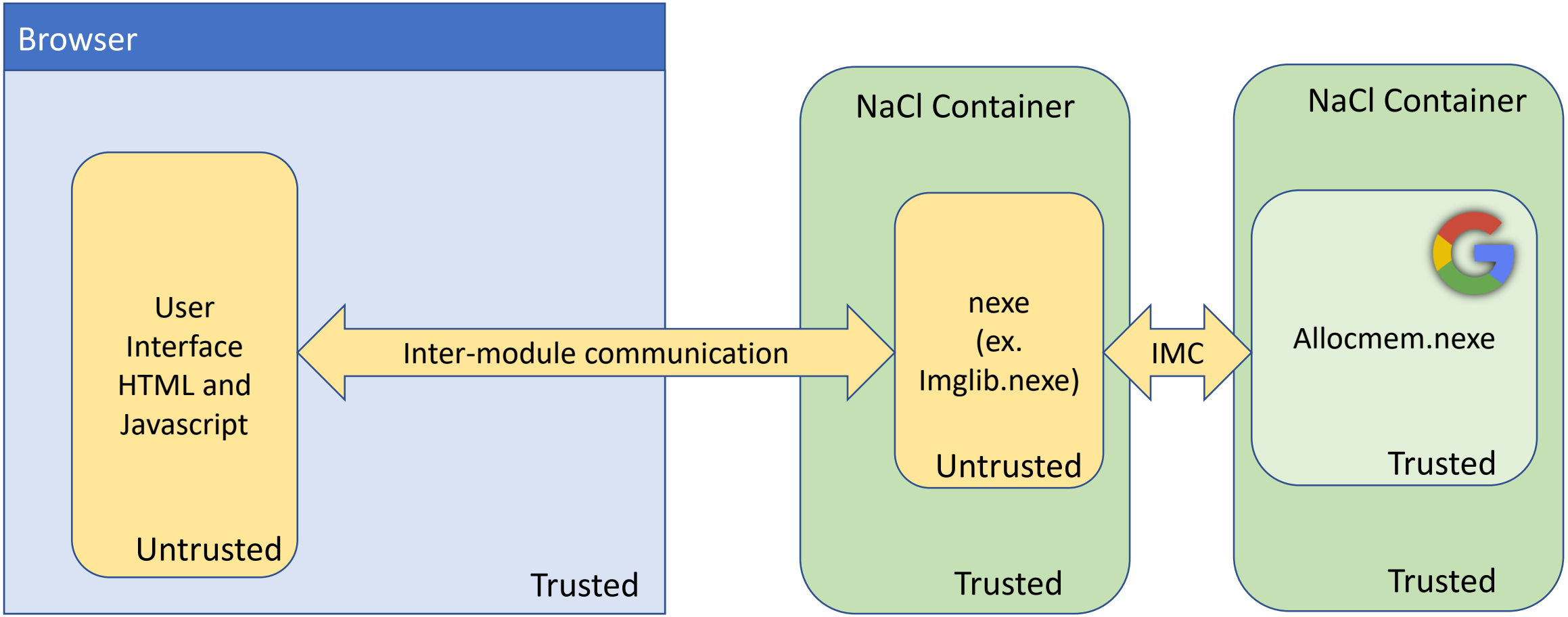
ALU

halt



Disallowed instructions (some more examples)

- `syscall` and `int`: untrusted code should not invoke the OS directly
- All instructions that modify the x86 state (ex. `lds`, far calls, etc.)
- `ret`. Returns are implemented with a sandboxing sequence that ends with an indirect jump



Other trusted modules: threads, messaging, …

2 Parts to Security

No disallowed instructions

All code and data access is in the module bounds

NOT | JUMP | ADD | SUB | XOR | JUMP | …

0 256MB

Variable Instruction Length!

```
25 CD 80 00 00
```

```
int $ 0x80
and %eax, 0x000008CD
```

Example credit to N. Zeldovich

2 Parts to Security

No disallowed instructions

All code and data access is in the module bounds

NOT | JUMP | ADD | SUB | XOR | MUL

Reliable Disassembly

0 256MB

Variable Instruction Length!

```
25 CD 80 00 00
```

```
int $ 0x80
and %eax, 0x000008CD
```

Example credit to N. Zeldovich

NaCl has a set of alignment and structural rules such that

the native code module can be disassembled such that **all** reachable instructions are identified in disassembly.

Reliable Dissasembly

NOT | JUMP | ADD | SUB | XOR | JUMP | …

0 256MB

- Check every mult. of 32 is a valid instruction
- Systematically check instructions
- `JMP`: check target was seen

```
JMP %eax
```

```
AND $0xffffffe0, %eax
JMP %eax
```

Reliable Dissasembly

NOT | JUMP | ADD | SUB | XOR | JUMP | …

0 256MB

- Check every mult. of 32 is a valid instruction
- Systematically check instructions
- `JMP`: check target was seen

`JMP %eax` → `NaCl Pseudoinstruction`

Constraints for NaCl binaries

1. Once loaded into the memory, the binary is not writable, enforced by OS-level protection mechanisms during execution.
2. The binary is statically linked at a start address of zero, with the first byte of text at 64K.
3. All indirect control transfers use a `nacljmp` pseudo-instruction.
4. The binary is padded up to the nearest page with at least one `hlt` instruction (0xf4).
5. The binary contains no instructions or pseudo-instructions overlapping a 32-byte boundary.
6. All *valid* instruction addresses are reachable by a fall-through disassembly that starts at the load (base) address.
7. All direct control transfers target valid instructions.

NaCl has a very large and complex architecture…

- Modifier Compiler Toolchain
- Secure ELF Loader
- Disassembler and code verification
- Service Runtime
- Inner and outer sandboxes
- IMC (Inter-module communication)
  - SRPC (Simple Remote Procedure Call)
  - PPAPI (Pepper)
- Trampolines and Springboards
- …

Secure execution of native code in the web browser