Applying Language-based Static Verification in an ARM Operating System

Matthew Danish
Boston University
md@bu.edu

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What do we want?

Correctness

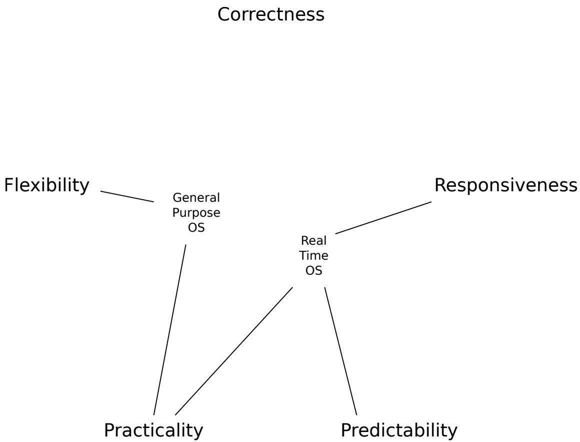
Flexibility

Responsiveness

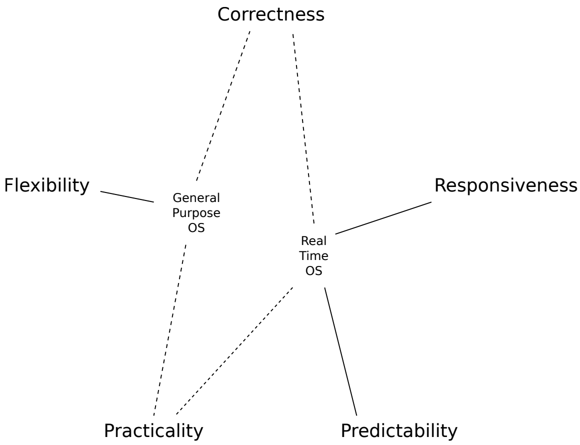
Practicality

Predictability

What do we want?



What do we want?



Programming Languages and Types

- Choosing or designing languages for systems
  - Unix: C
  - SPIN: Modula-3
  - Singularity: Sing#
  - seL4: Isabelle, Haskell and C
  - House: Haskell

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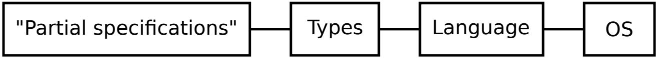
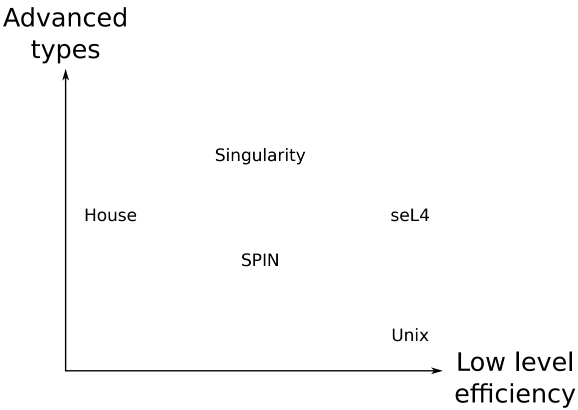
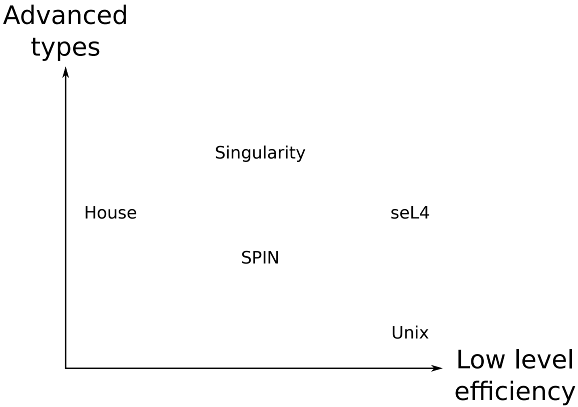



Advanced types
Singularity
House
seL4
SPIN
Unix
Low level efficiency



Can we have more advanced types and low level efficiency?

ATS

- ML-like, strong C integration, LF-style theorem proving
- Linear types (a.k.a. view types), dependent types
- Separation of proof-world and program-world,

  `(proof | program)`
- Practical, functional programming in system setting

Terrier OS

- ARM, TI OMAP4 MP-core, SMP, USB support
- Exploring advanced types in assisting OS development
- Compact and uncluttered design, with message-passing
- Work in progress

Challenges

- Bringing high level functional programming into OS
- Using advanced types to tackle common problems
- Interfacing with the low level code where needed
- Avoiding performance impacts

Functional programming

- Nested functions
- Tail recursion elimination
- Higher order functions
- Style

Resource management

- Linear reasoning: avoid memory leaks
- "Must be used once and exactly once"
- Typical pattern: allocate, transform, and release

```
let val (proof_var | pointer_var) = alloc ()
    val x = do_something (proof_var | pointer_var)
in free (proof_var | pointer_var)
```

Synchronization

- Linear reasoning for synchronization
- Ensure proper lock management
- Correct sequencing of steps

```
let val (outer | _) = outer_lock () in
  let val (inner | _) = inner_lock (outer | ) in
    ...
  let val (outer | _) = inner_unlock (inner | ) in
outer_unlock (outer | )
```

Safe use of pointers

- Concept: "value of type `t` is stored at address `l`"
- ATS "`@`-view": `type @ address`

```
fun alloc_pair(): [l: addr] ((int, int) @ l | ptr l)

fun free_pair {l: addr} (pf: (int, int) @ l | p: ptr l)
```

- Pointers: a "dependent type" i.e. a type indexed by a value
- In this case: the value is the address
- The "`@`-view" validates the pointer

Array bounds checking

- Integer constraint solver
- Automatic bounds checks
- `array`: dependent type indexed by length
- Array access must be within $0 \leq i < n$

```
fun f {n: int | n > 3}
      (A: array (int, n), len: int n): int =
  let val x = A[0] in
    if len > 4 then x + A[4] else x
```

Integer constraints

- Not just limited to arrays
- Example from scheduler
- "exists tick t such that $t > \mathit{now}$"

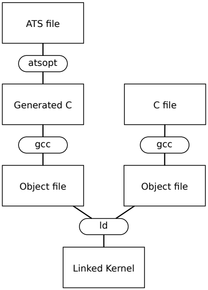
```
val [now: int] now: tick now = timer_32k_value()

fun is_earlier_than {n, m: nat}
    (tn: tick n, tm: tick m): bool (n < m)
...
val future: [t: int | t > now] tick t = ...
```

Avoiding overhead

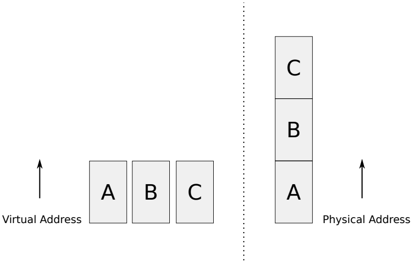
- Erasure of statics
- Flat types, C data representation
- Templates

ATS integration



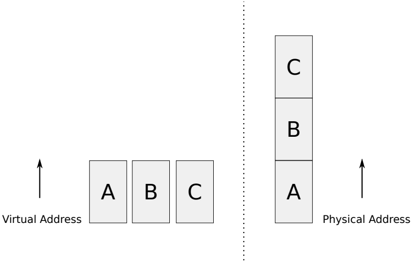
- ATS acts as preprocessor
- No run-time and minimal static support
- ATS in both kernel and program components

Protection



- Hardware memory protection optional
- Can rely on hardware protections when needed
- Or can switch to static verification when ready

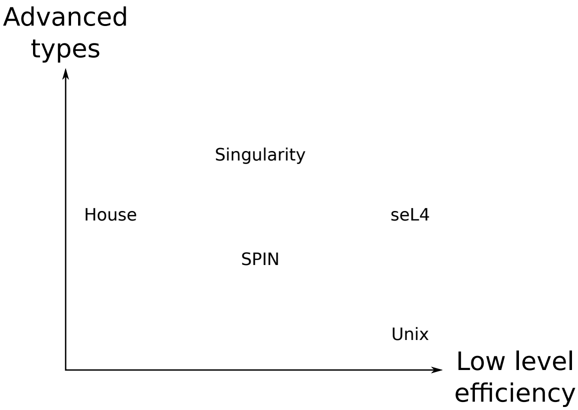
Protection



- All programs take advantage of ELF features for relocation
- Kernel has load-time linker which rewrites binary
- Can rewrite binaries into the two different memory models

Putting it together

- The role of type systems in OS development
- Application of advanced types for better assurance
- Incremental approach to verification
- Straightforward machine translation to C
- Depends on compiler and hardware correctness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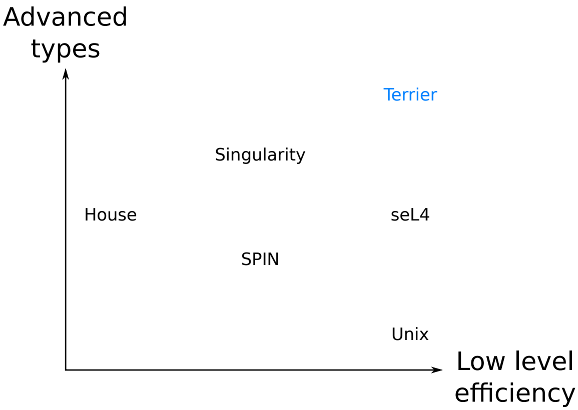
Advanced types
Terrier
Singularity
House
seL4
SPIN
Unix
Low level efficiency

seL4 and Terrier

seL4

- Haskell prototype, Isabelle specification, refinement proof between specification and C
- Entire kernel, big effort
- Top-down

Terrier

- Written directly in C/ATS mix, ATS types
- Flexible, selective effort
- Bottom-up

Future work

- Writing more proofs
- Adding further hardware support
- Deploying on an experiment