User-Guided Device Driver Synthesis

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The joys of driver development

- Drivers are hard to write
- … and even harder to debug
- They often delay product delivery
- … and are the most common source of OS failures

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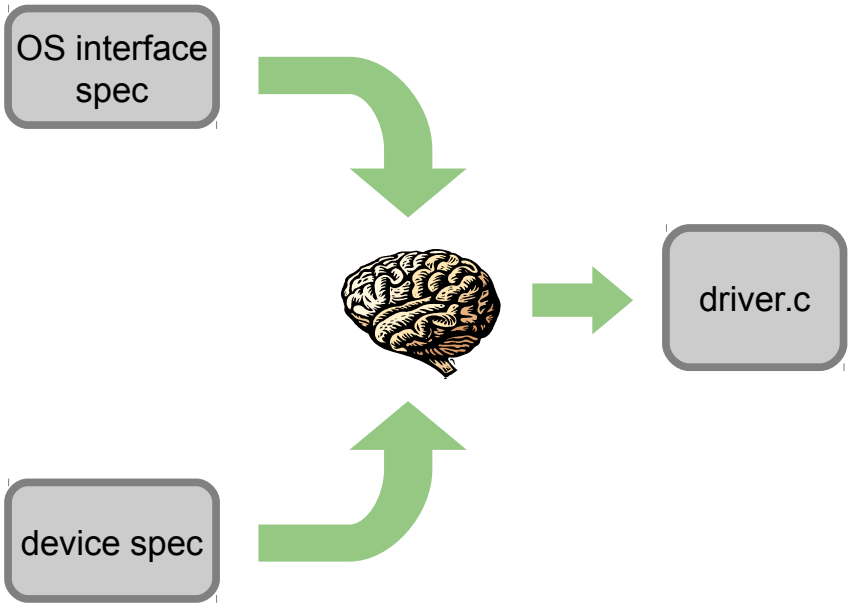
Funded by a research grant from Intel

Observation

- Driver development is a mechanical task
- Can in principle be automated



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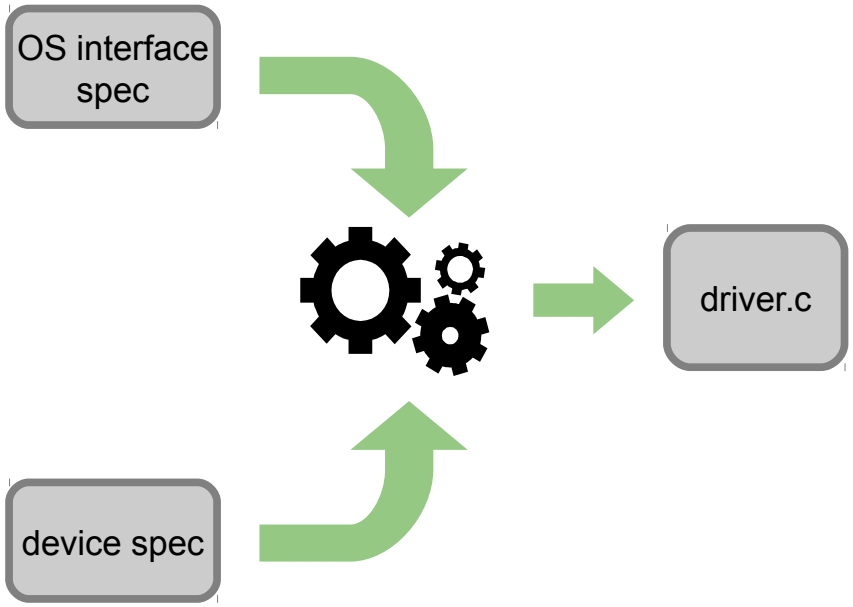
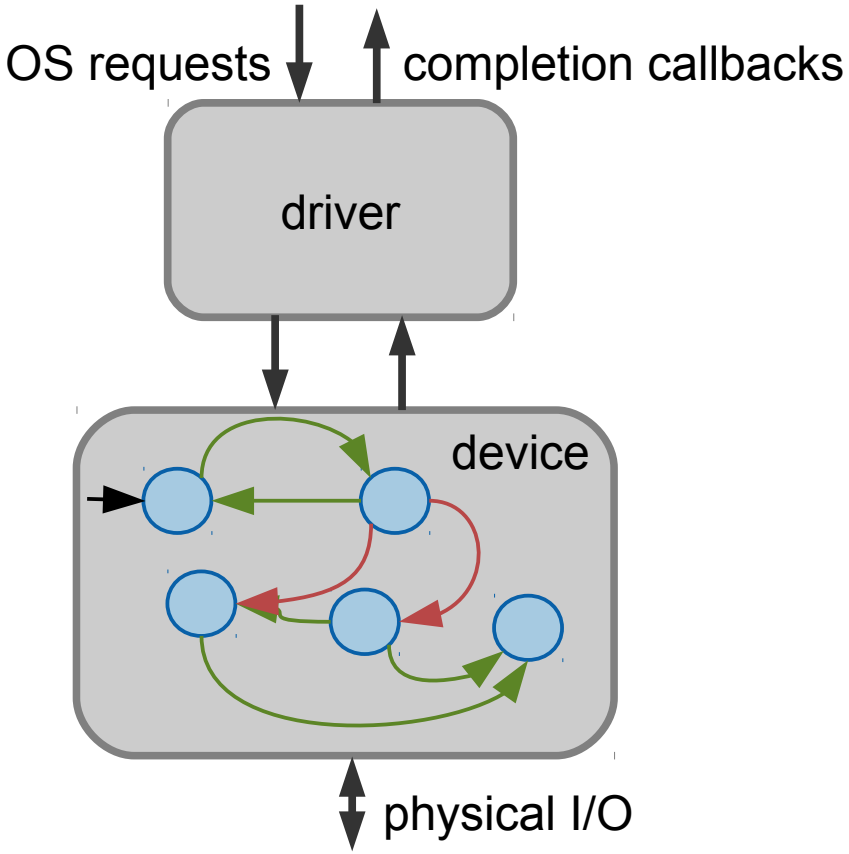


Driver Synthesis as a Game

- Driver synthesis can be formalised as a two-player game: *driver* vs *(device + OS)*



Motivation

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Addresses an important problem

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A simple, neat idea

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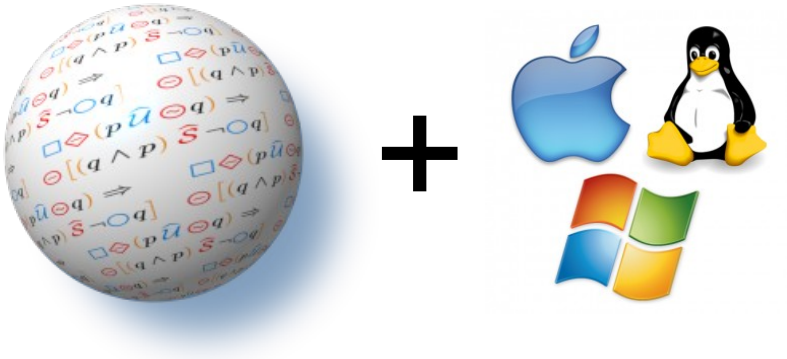
One of few applications of FM to OS (beyond verification)



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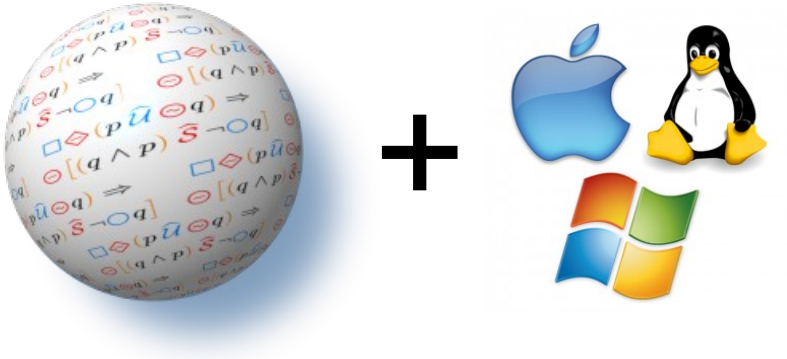
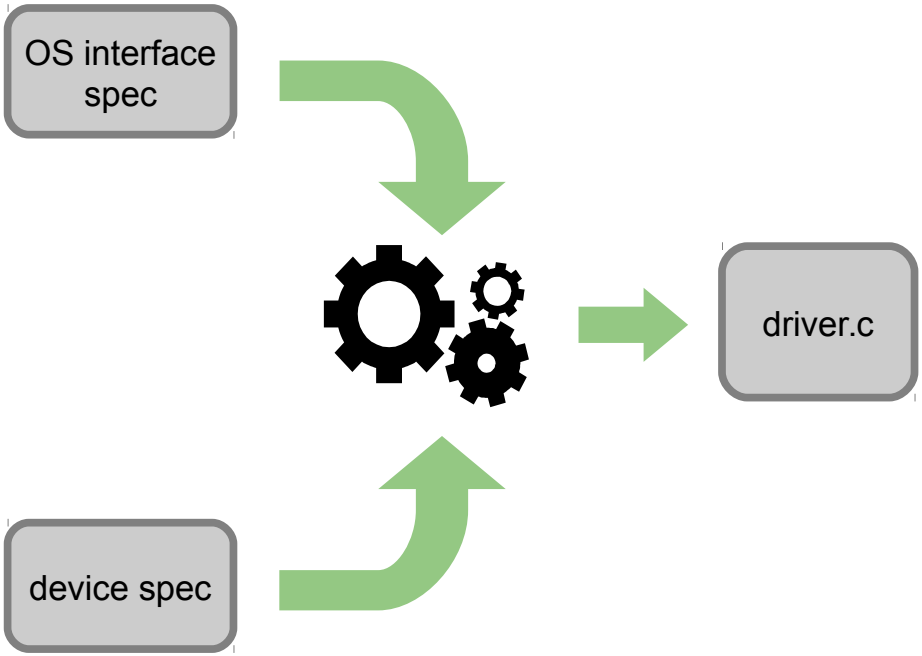
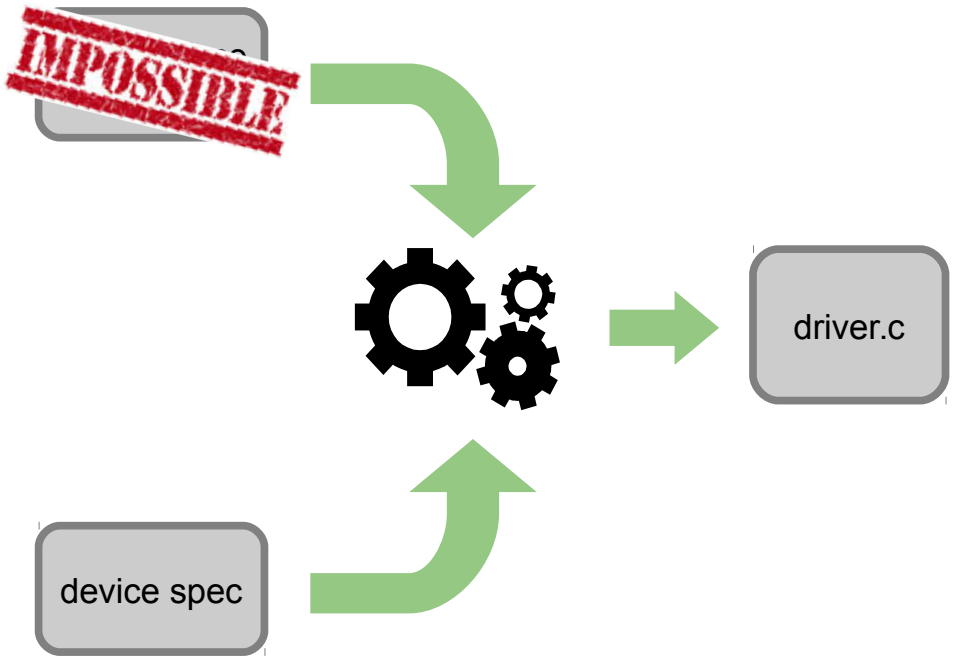
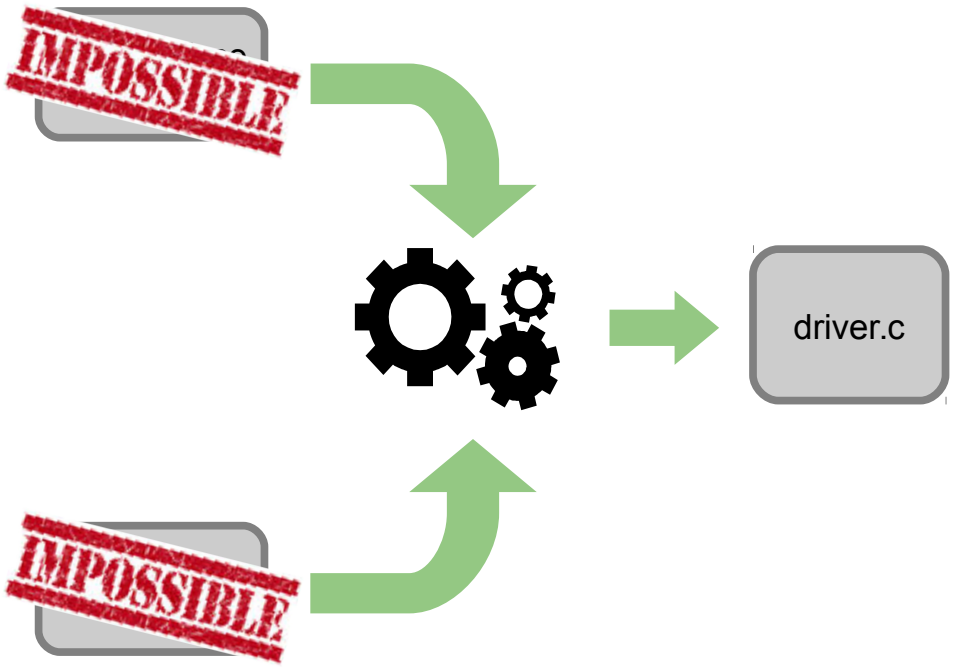


Considered impossible


OS interface spec
device spec
driver.c


IMPOSSIBLE
driver.c
device spec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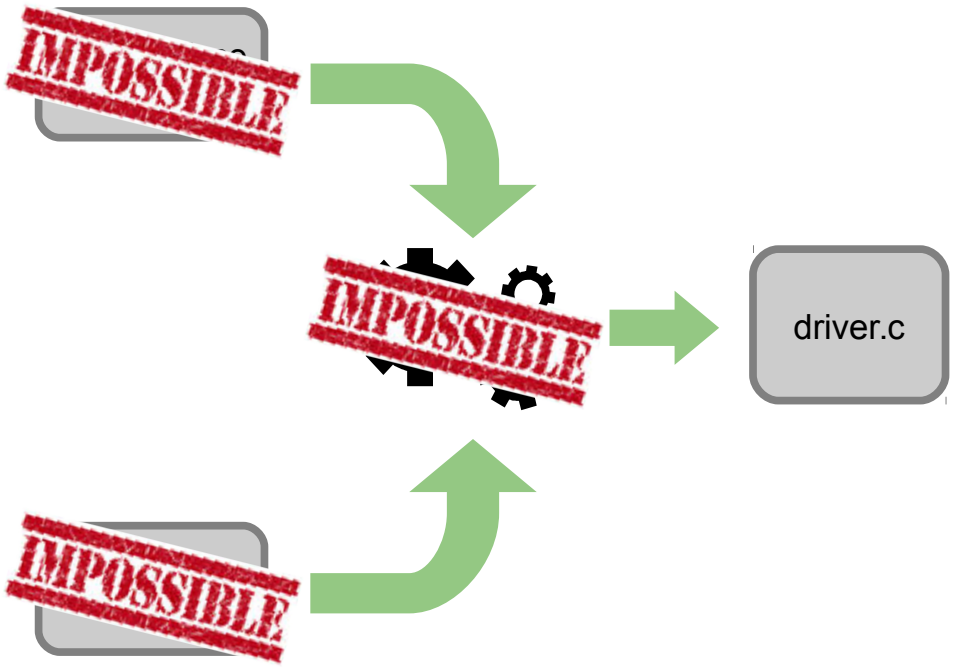
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driver.c

Driver Synthesis as a Game

Driver Synthesis as a Game

`request:set_time( 19:30:00)`

Driver Synthesis as a Game


```
request:set_time( 19:30:00)

write_hours( 19)
```

Driver Synthesis as a Game


```
request:set_time( 19:30:00)
write_hours( 19)
write_minutes(30)
```

Driver Synthesis as a Game


```
request:set_time( 19:30:00)
write_hours( 19)
write_minutes(30)
write_seconds(00)
```

Driver Synthesis as a Game


```
request:set_time( 19:30:00)
write_hours( 19)
TICK
```

Driver Synthesis as a Game


```
request:set_time( 19:30:00)
write_hours( 19)
TICK
```

Driver Synthesis as a Game

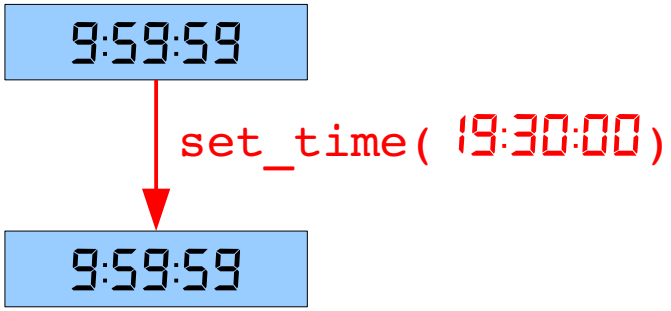

```
request:set_time( 19:30:00)
write_hours( 19)
TICK
write_minutes(30)
write_seconds(00)
```

Driver Synthesis as a Game


```
request:set_time( 19:30:00)
STOP
write_hours( 19)
write_minutes(30)
write_seconds(00)
START
```

Driver Synthesis as a Game

Driver Synthesis as a Game



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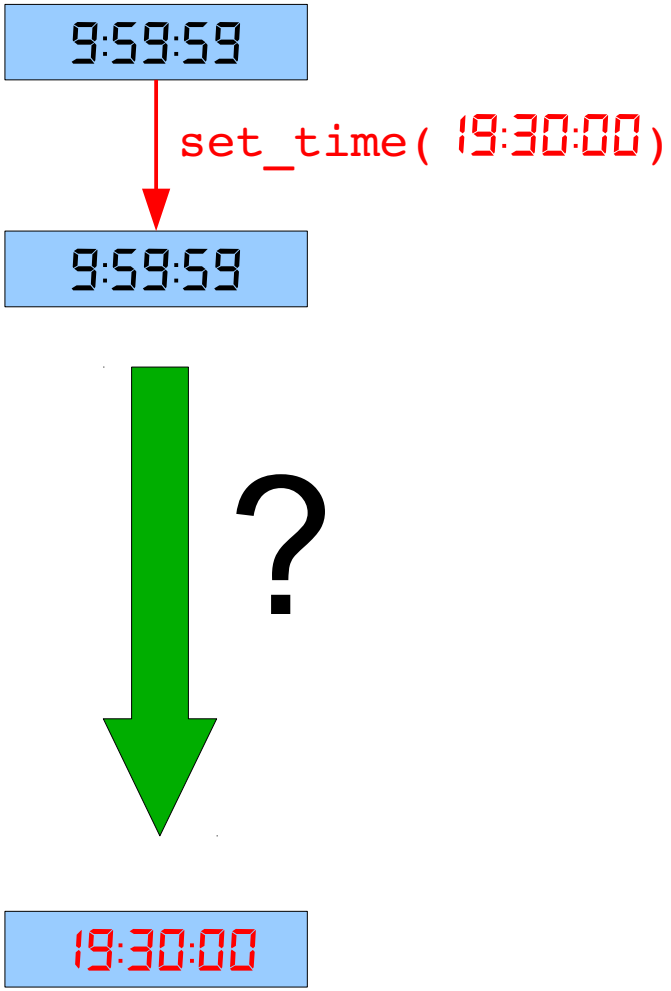

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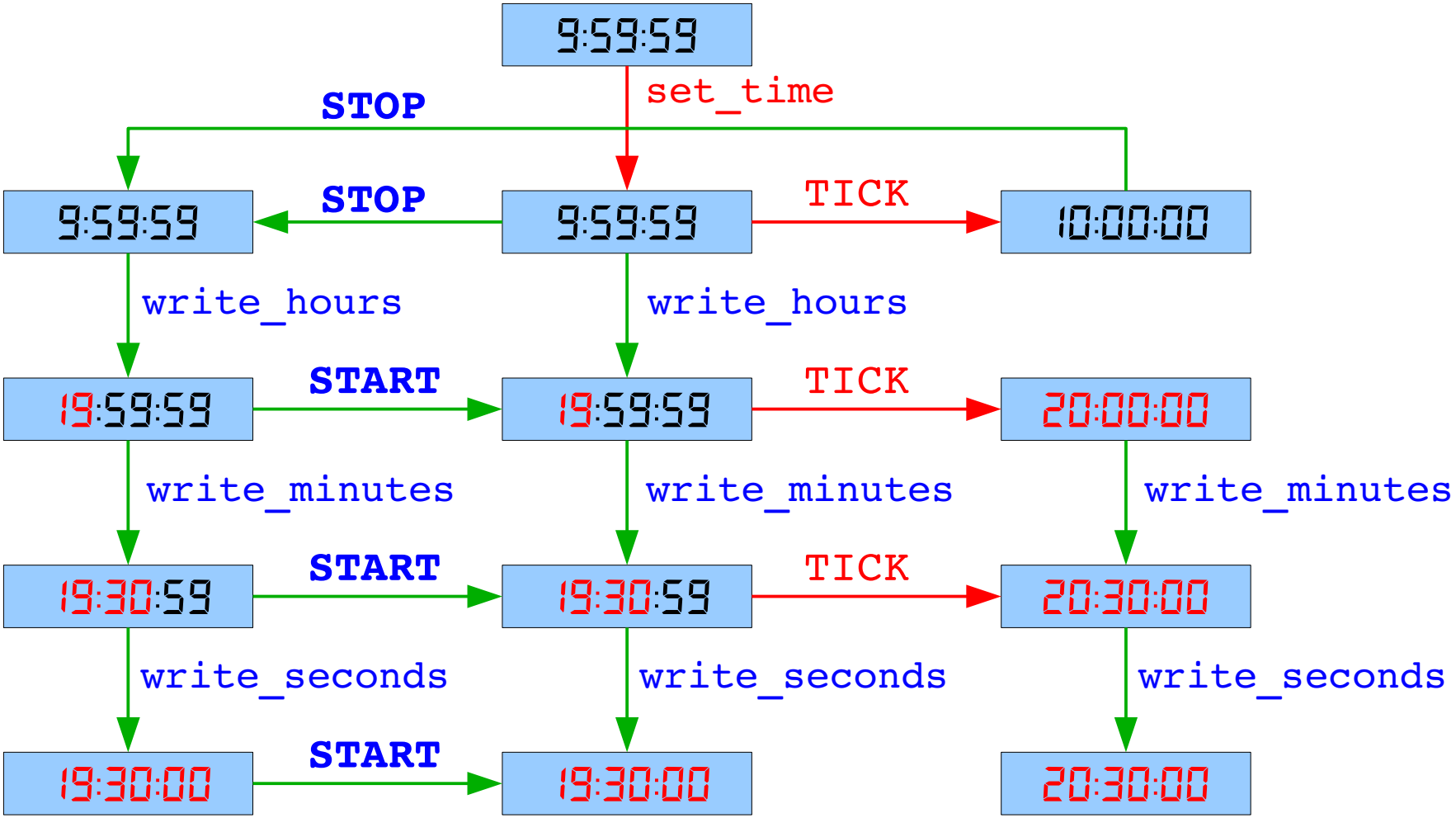

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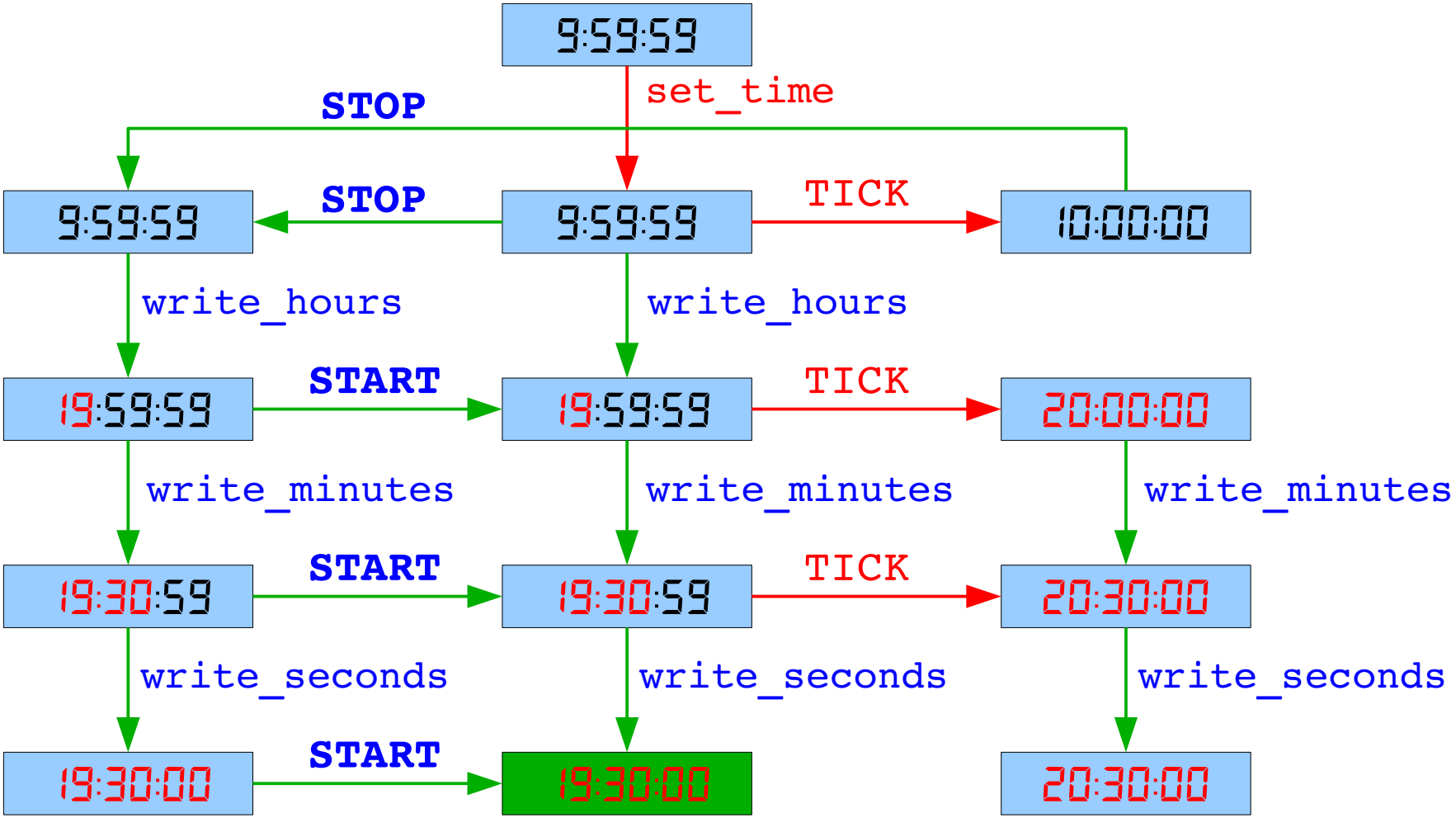

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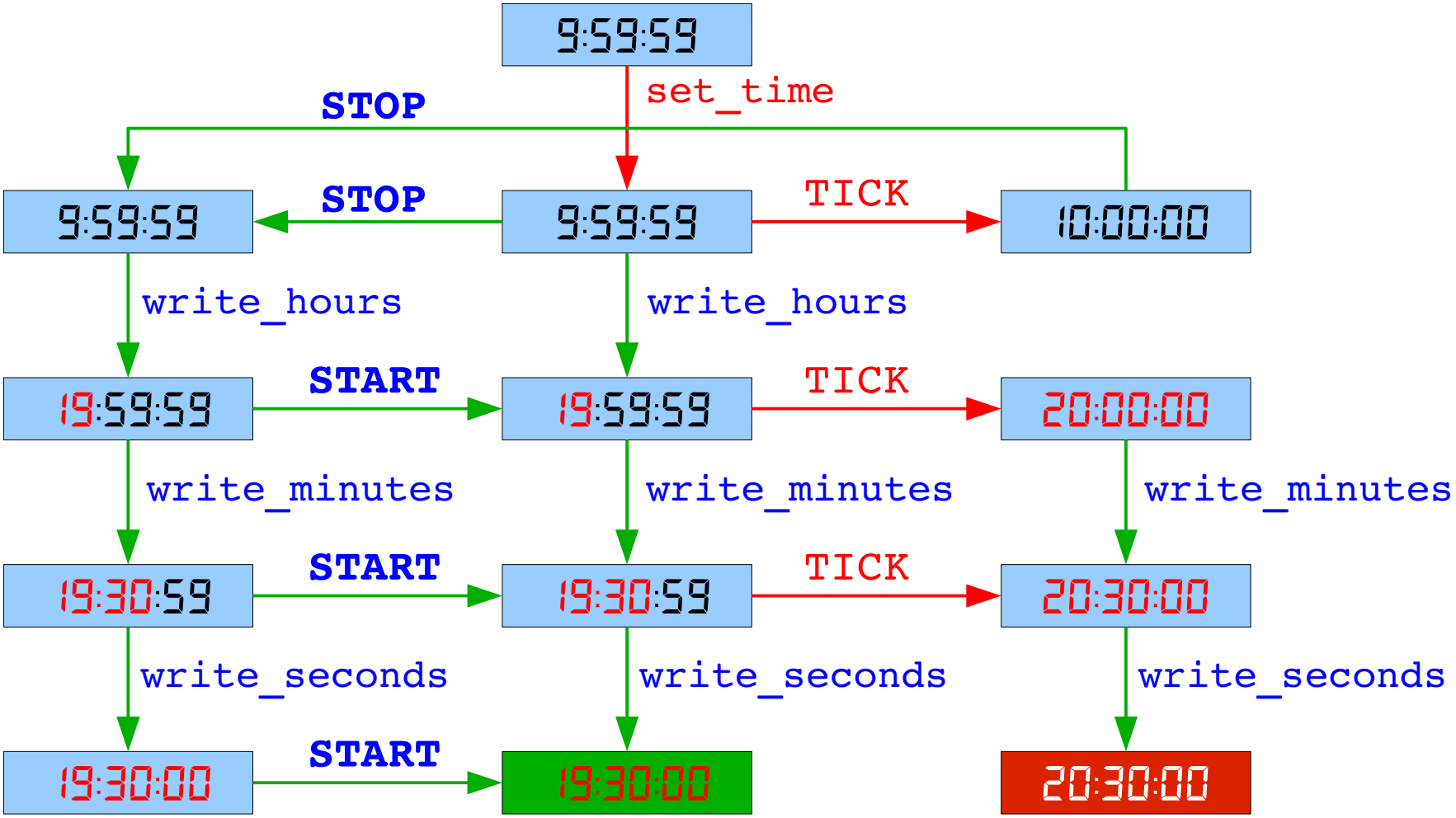

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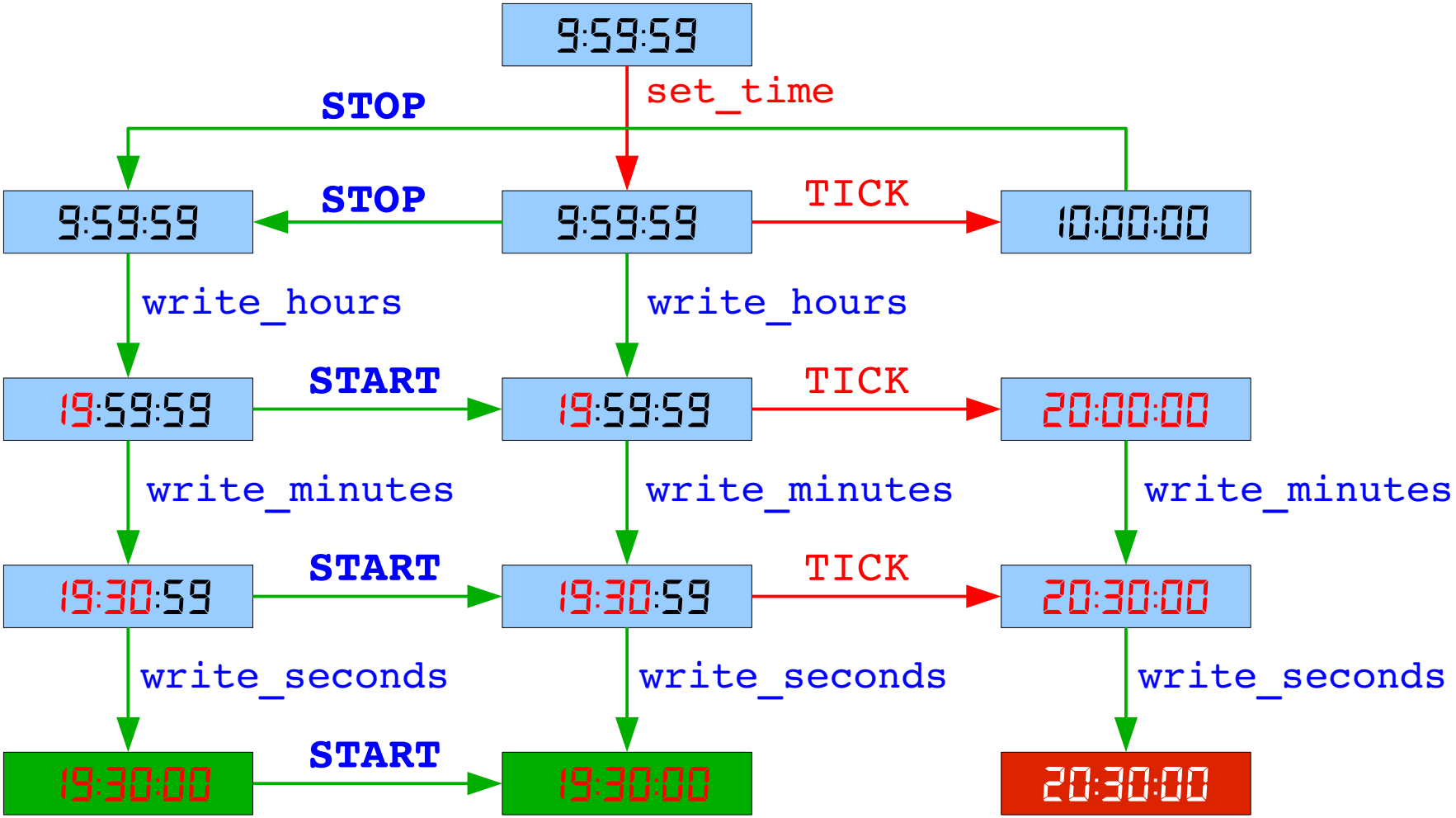

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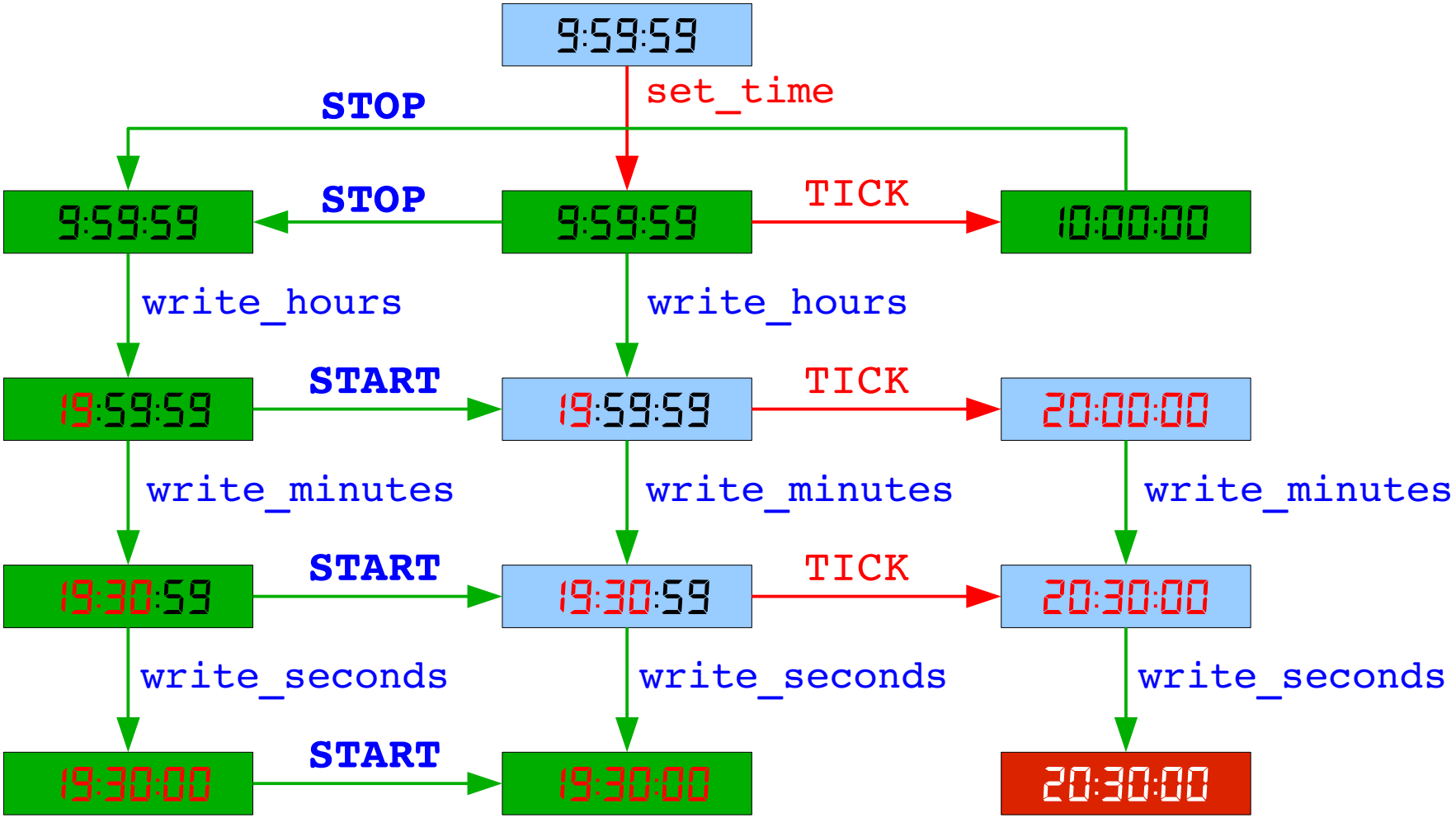

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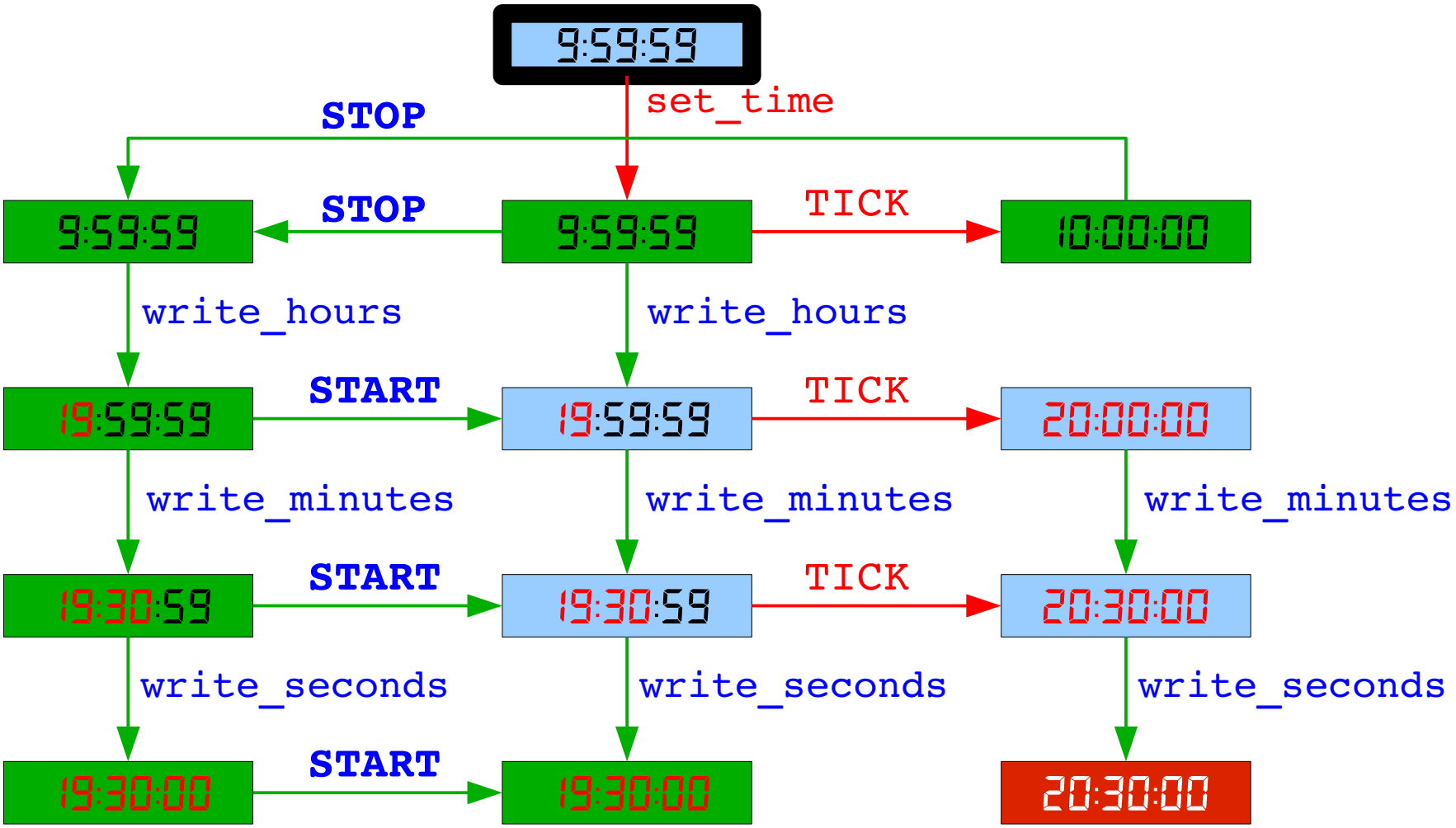

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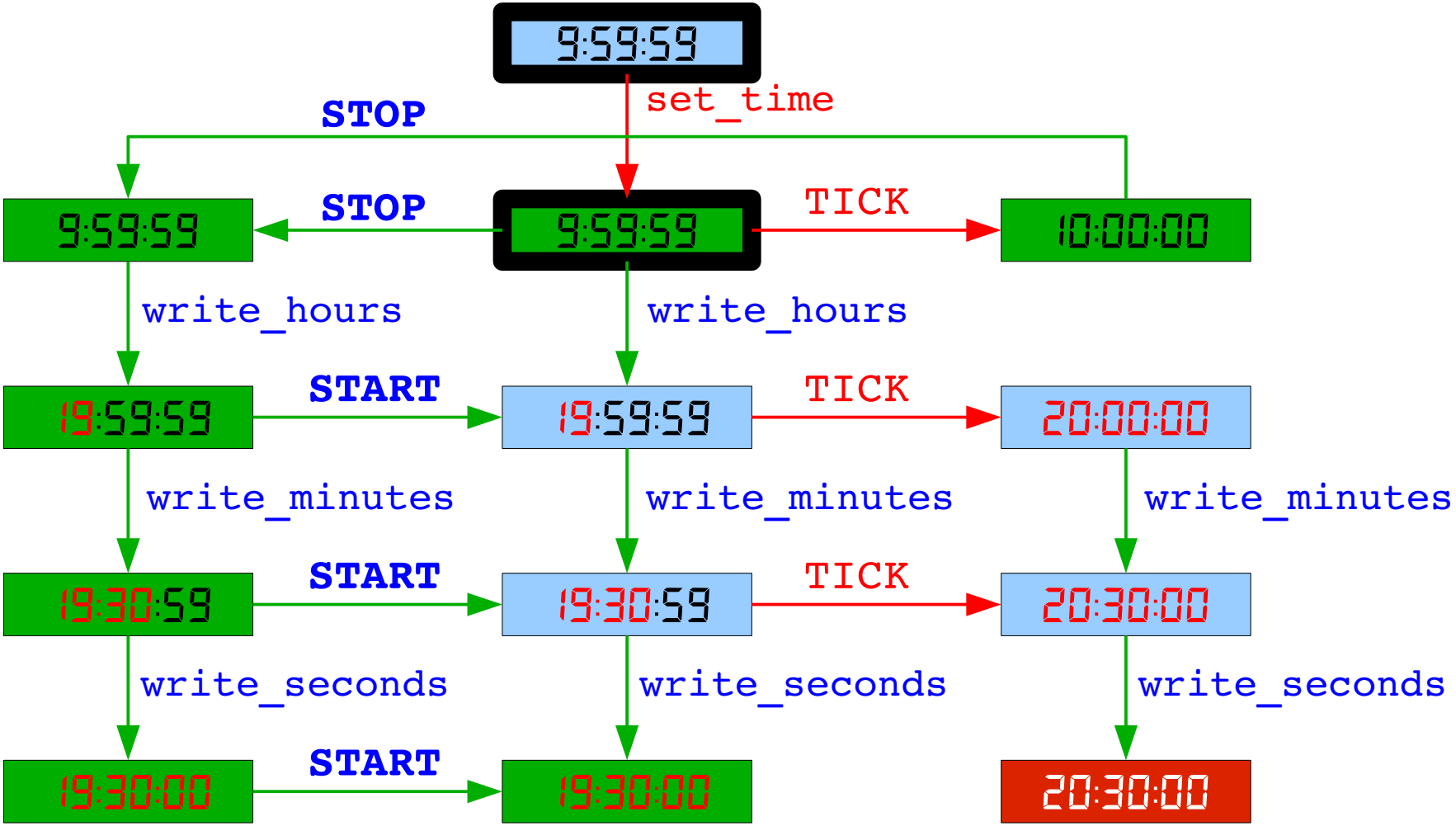

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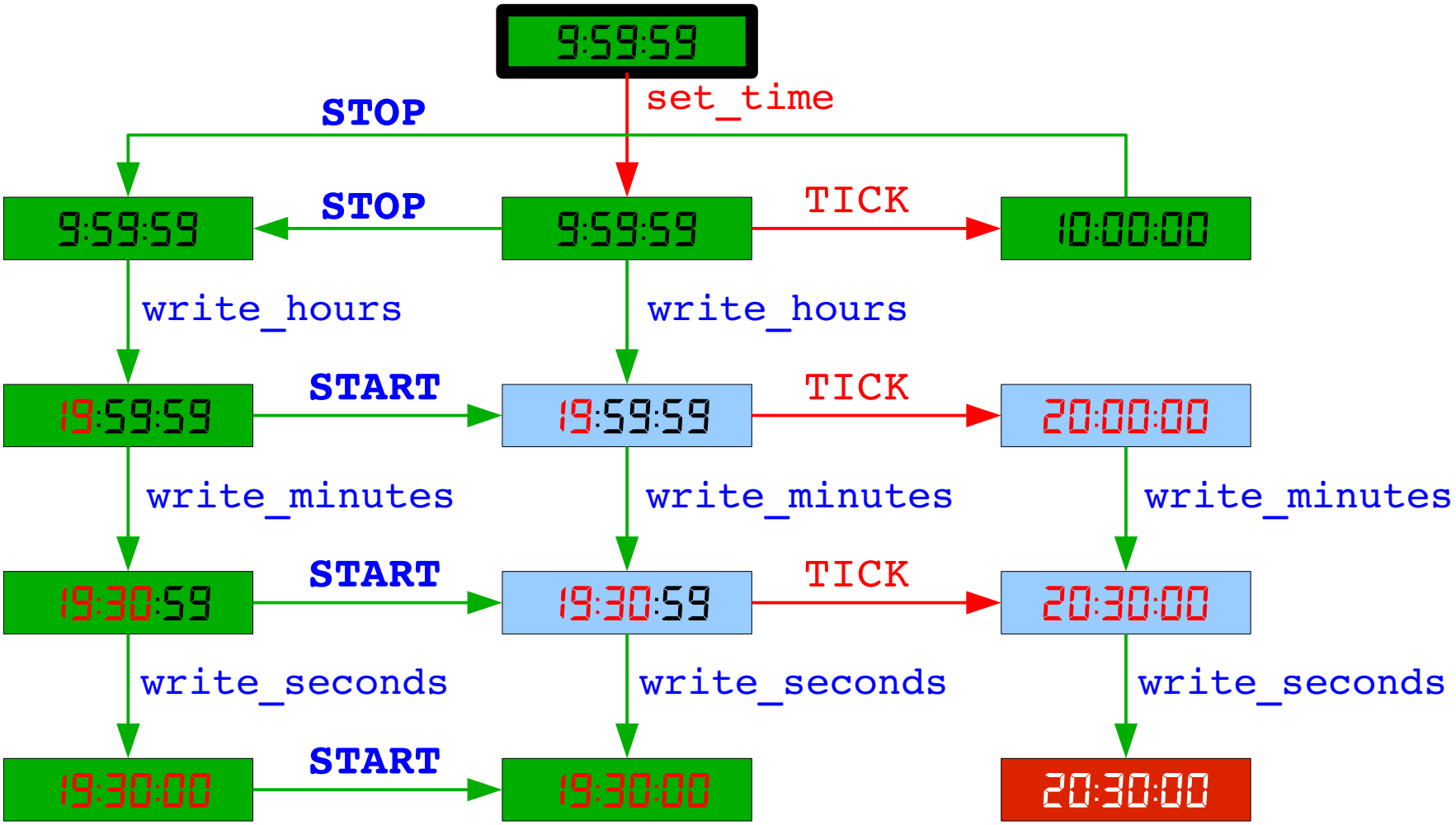
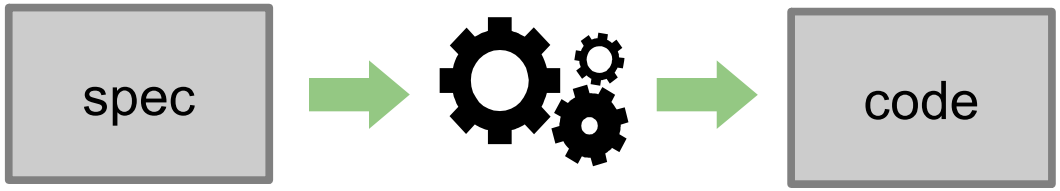


Termite Tool Demo

Push-Button Synthesis (SOSP'09)

- **In theory:**



correct spec => correct implementation

- **In practice:** (based on our experience) taking control away from the developer is not a good idea

Push-Button Synthesis (SOSP'09)

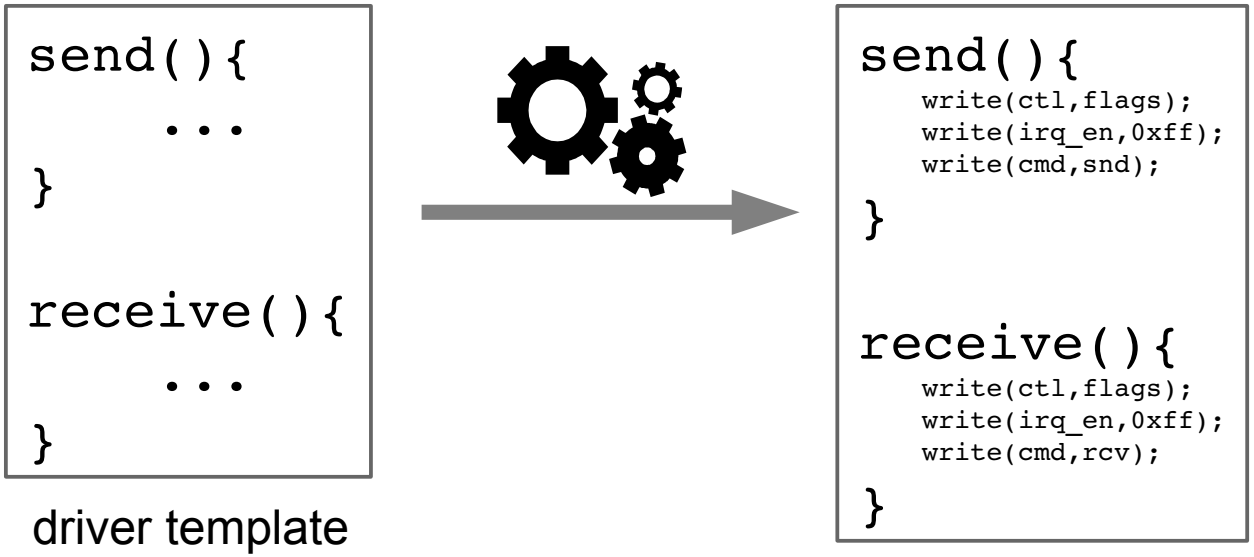
- Choosing a preferred implementation method is hard (e.g., polling vs interrupts)
- Non-functional properties (power, performance, timing, etc.) are hard to enforce
- Achieving “nice” code structure is hard

User-Guided Synthesis

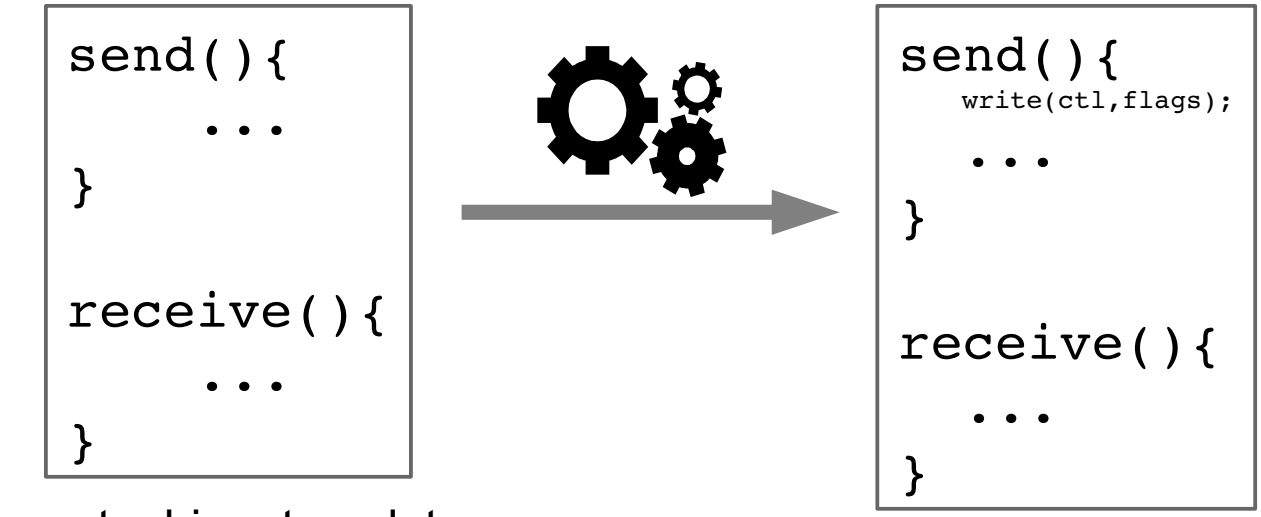
- The user is in control
  - can write arbitrary manual code or …
  - arbitrarily alter automatically generated code
- Synthesiser works as smart auto-complete
  - can generate a statement, a function, or even the whole driver (on demand)
  - never alters user code
  - completes synthesised+manual code to a correct implementation when possible
- The tool enforces correctness

Demo (continued)

Guided Synthesis
Scenario 1: Fully Automatic Synthesis



Guided Synthesis
Scenario 2: Hybrid Approach



empty driver template

partially
synthesised driver

Guided Synthesis
Scenario 2: Hybrid Approach

```
send(){
    write(ctl,0);
    ...
}

receive(){
    ...
}
```

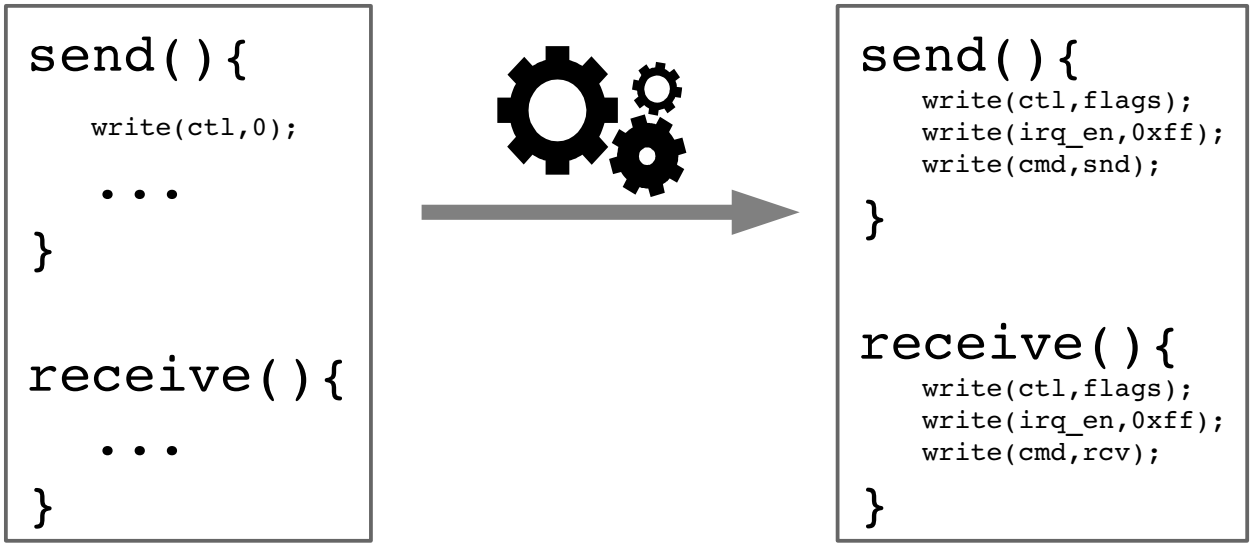
modified driver template

```
send(){
    write(ctl,flags);
    ...
}

receive(){
    ...
}
```

partially
synthesised driver

Guided Synthesis
Scenario 2: Hybrid Approach



modified driver template

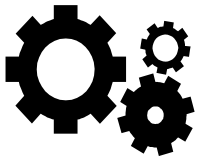
synthesised driver

Guided Synthesis
Scenario 3: Verification

```
send(){
    write(ctl,flags);
    write(irq_en,0xff);
    write(cmd,snd);
}

receive(){
    write(ctl,flags);
    write(irq_en,0xff);
    write(cmd,rcv);
}
```

manually developed driver



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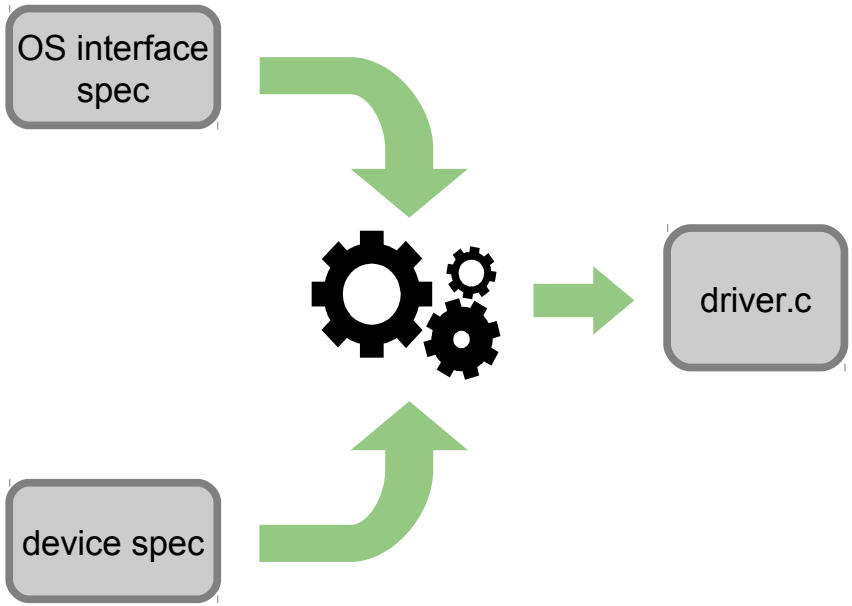
Obtaining Specs for Driver Synthesis



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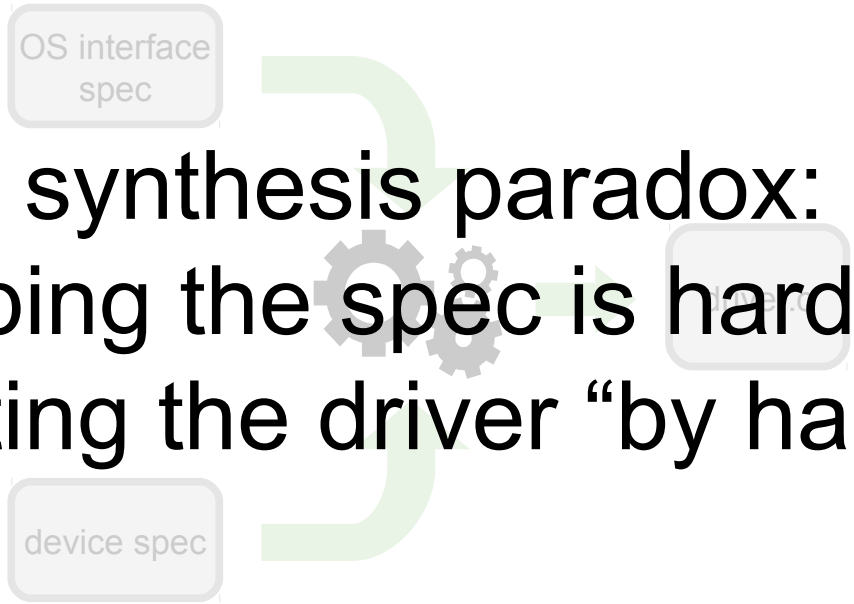
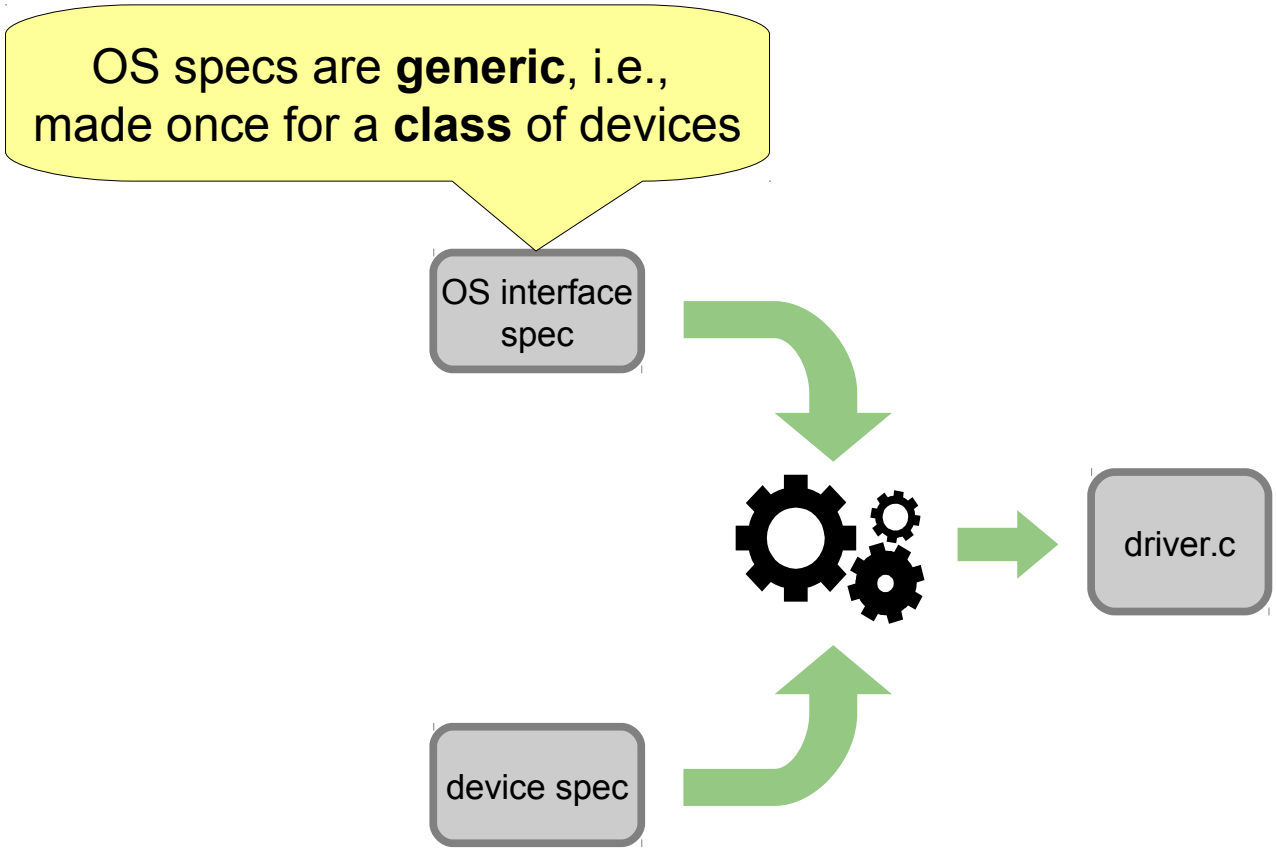


The synthesis paradox: developing the spec is harder than writing the driver “by hand”.

Obtaining Specs for Driver Synthesis



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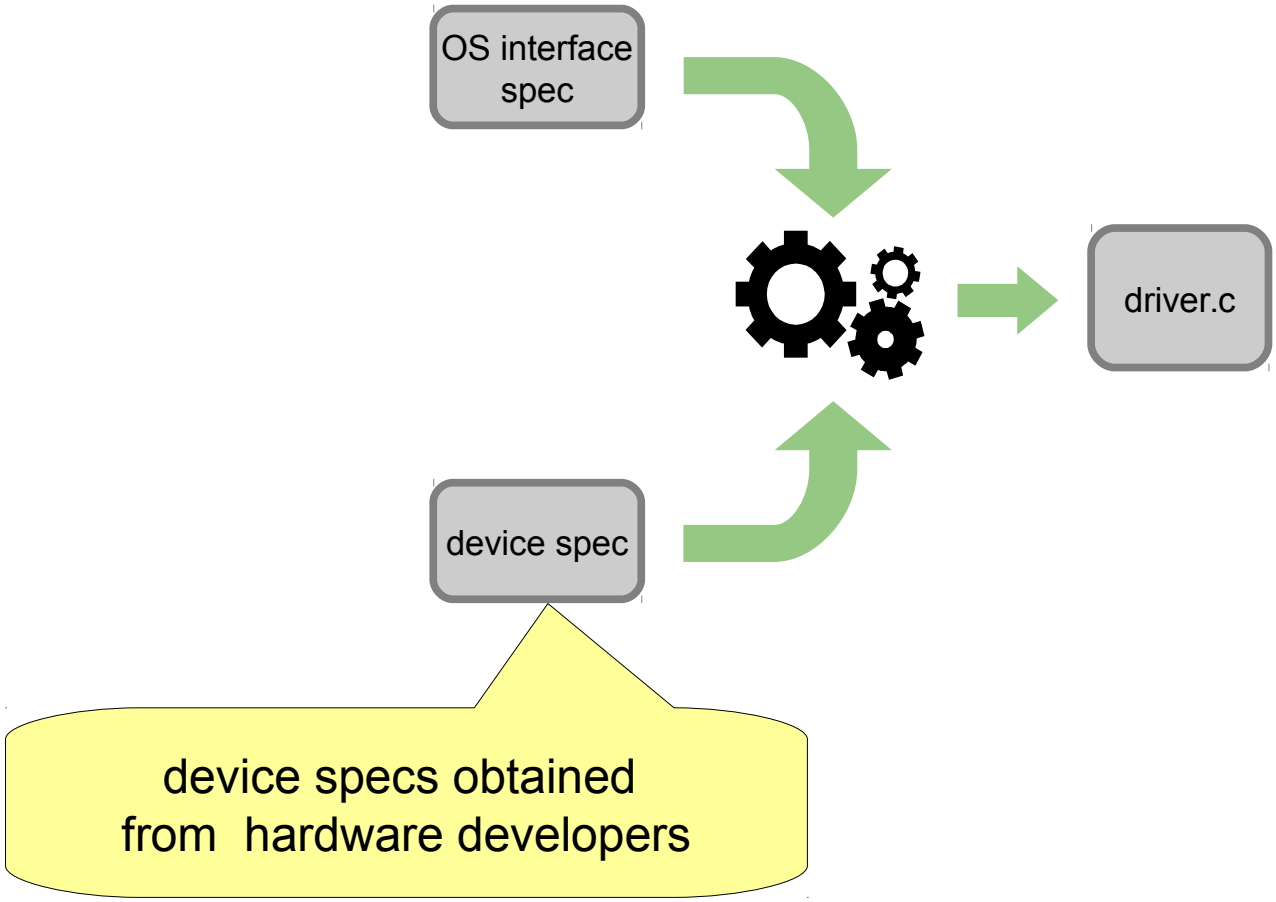

Synthesised Drivers

Device	Synthesis time (s)	locs
Real-time clock	74	56
IDE	71	94
STM32F103RB UART	309	74
exynos 5 UART	177	35
STM32F103RB I2C	39	119
exynos 5 I2C	40	77
webcam	190	113
SPI	15	27

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Scope and Limitations

- Focus on synthesising device control logic
  - Resource allocation, binding to OS interfaces, etc., must be written manually or synthesised using different techniques
- Sequential synthesis
  - Synchronisation synthesis as a separate step (jointly with CU Boulder and IST Austria)
- No DMA support
  - WiP

Summary

- Termite automates tedious driver development
- The user has full control over the source code, but Termite enforces correctness

`https://github.com/termite2`

`http://termite2.org`

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- Termite automates tedious driver development
- The user has full control over the source code, but Termite enforces correctness
- Driver synthesis is less impossible than previously believed

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