SYNCHRONOUS LANGUAGES

LECTURE 14
THE BLECH PROGRAMMING LANGUAGE

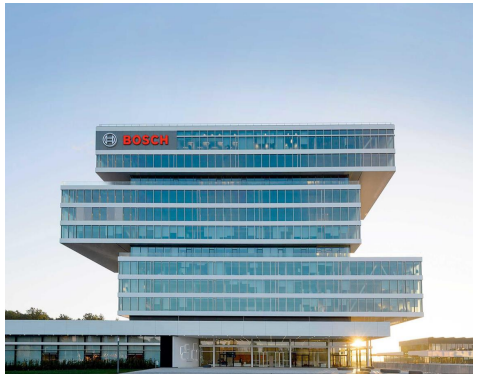
16 JUNE, 2020
FRIEDRICH GRETZ
BOSCH CORPORATE RESEARCH

BOSCH

Overview

- Today's speaker
- **Why is synchronous programming interesting for Bosch?**
- Design goals
- Blech – as of now
- Application examples
- Outlook on planned features
- Additional remarks

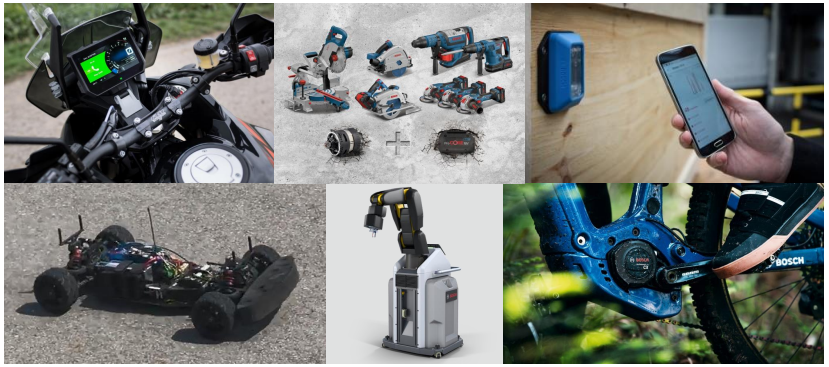
Today's speaker



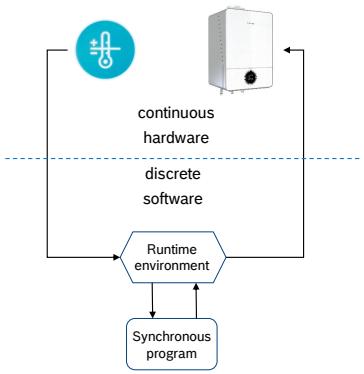
Dr. Friedrich Gretz
Robert Bosch GmbH
Corporate Research in Renningen

Friedrich.Gretz@de.bosch.com
www.blech-lang.org

Why is synchronous programming interesting for Bosch?
Reactive, embedded software everywhere!



Abstract view of a reactive system
Where do we use a synchronous language?



- Environment communicates asynchronously with physical world, drives synchronous programs
- A program is executed is *steps*
  - Assume a step takes no time (happens instantaneously)
  - No change of input data throughout computation
- A sequence of steps is called a thread of execution
- Threads can be composed concurrently
  - Accesses to shared data happen in a deterministic, causal order

Overview

- Today's speaker
- Why is synchronous programming interesting for Bosch?
- **Design goals**
- Blech – as of now
- Application examples
- Outlook on planned features
- Additional remarks

Do we need a new synchronous language?
Available alternatives do not fulfill our requirements

- Céu — purely event-triggered, no causality, soft-realtime
- Esterel — no longer supported, not sequentially constructive, not separately compilable
- Lustre — not imperative, good for evaluating control loop equations but less intuitive for describing step-wise, mode switching behaviour
- SCCharts — automata centric view

Create a synchronous imperative language – Blech

Design goals
Requirements

- Clear focus
  - Software
  - Reactive
  - Resource-constrained
  - Real-time
  - Scalable
- Domain orientation
  - Embedded
  - Control intensive systems
  - Computations and switching behaviour
  - Intertwined functionality
- Compatibility
  - Integration **of** legacy code
  - Integration **in** legacy code
  - Support separate compilation
- Deployment
  - Efficient code generation
  - Safe code generation
  - Integrate synchronous "execution shell" with existing real-time OS environments
  - Deployment on multi-core platforms
- Developer Orientation
  - Readable
  - Clear semantics
  - Stateflow in controlflow
  - Structured data
  - Code structuring, information hiding
  - Safe and modern type system
- Testing & Safety
  - Deterministic, repeatable testing
  - Integrate with existing simulation frameworks
  - Reduce false positives in static code analysis
  - Provide more guarantees, e.g. through causality

Overview

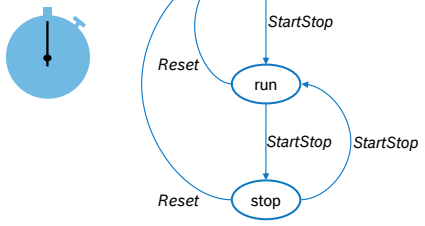
- Today's speaker
- Why is synchronous programming interesting for Bosch?
- Design goals
- **Blech – as of now**
- Application examples
- Outlook on planned features
- Additional remarks

Blech
Concurrent composition of behaviours over time

```
/// Main Program
@[EntryPoint]
activity Main (isPressedStartStop: bool,
               isPressedReset: bool)
   var display: Display
   cobegin // render
      repeat
         show(display)
         await true
      end
   with // control
      run StopWatchController(isPressedStartStop,
                              isPressedReset)
                             (display)
   end
end
```

- Execution model
  - Concurrent behaviours run in synchronised steps
- Causal order
  - first, update display data
  - second, show display
- Code generation
  - sequential code
  - Statically ordered by the compiler

Blech
Mode transitions as synchronous control flow




```
activity stopWatchControl (isPressedStartStop: bool,
                           isPressedReset: bool)
                          (display: Display)
   when isPressedReset reset
      // init
      resetToZero()(display)
      if not isPressedStartStop then
         await isPressedStartStop
      end
      repeat
         // run
         repeat
            await true
            increment()(display)
         until isPressedStartStop end
         // stop
         await isPressedStartStop
      end
   end
end
```


Blech
Concurrency in detail

```
cobegin [weak]
   . . .
with [weak]
   . . .
end
```

do a step here

and

do a step there

```
cobegin
   run A(x)(z)
with
   run B(y)(x)
end
```

in every reaction:

"write before read!"

```
cobegin
   run A(x)(z)
with
   run B(y)(z)
end
```

write-write conflict

reject compilation

```
cobegin
   run A(x)(z)
with
   run B(z)(x)
end
```

write-read cycle

reject compilation

```
cobegin
   run A(x)(z)
with
   run B(prev z)(x)
end
```

solution

use previous value

Blech
Concurrency in detail

```
…
cobegin
    …
with
    …
    cobegin
        run A(x)(z)
    with
        …
    end
    …
with
    run B(prev z)(x)
end
…
```

- Cobegin may have any fixed number of blocks
- Cobegin is orthogonal: it can be arbitrarily nested
- Subprograms are **black boxes** with interfaces, may be **compiled separately**
- **Interfaces** tell what data types are expected **and** whether data is only **read** or also **written**
- Causal **scheduling is dealt with locally** at call site
- Causality issues arise and may be debugged and **fixed within one cobegin statement**!

Blech
Use case for weak branches

runs indefinitely, unless terminated

```
cobegin weak
    run BlinkLED(...)(...)          // no arguments for readability
with
    run WaitForKeyStroke(...)(...) // no arguments for readability
end
```

eventually terminates (if the system is to make any progress at all)

Blech
Concurrency in detail

```
cobegin
    run A(x)(z)
with
    run B(y)(x)
end
```

cobegin statement terminates when…

A **and** B have finished all their reactions

- start: cobegin, A, B
- A, B
- A, B; finished: A
- B; finished: B, cobegin

```
cobegin weak
    run A(x)(z)
with
    run B(y)(x)
end
```

B has finished all its reactions; A is possibly aborted

- start: cobegin, A, B
- A, B
- A, B; finished: A
- B; finished: B, cobegin

```
cobegin
    run A(x)(z)
with weak
    run B(y)(x)
end
```

A has finished all its reactions; B is possibly aborted

- start: cobegin, A, B
- A, B
- A, B; finished: A, B, cobegin

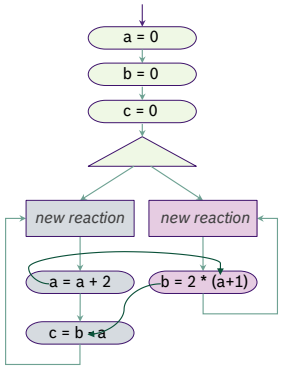
```
cobegin weak
    run A(x)(z)
with weak
    run B(y)(x)
end
```

A **or** B has finished all its reactions; the other one is possibly aborted

- start: cobegin, A, B
- A, B
- A, B; finished: A, B, cobegin

Blech
Compiling activities to sequential C functions

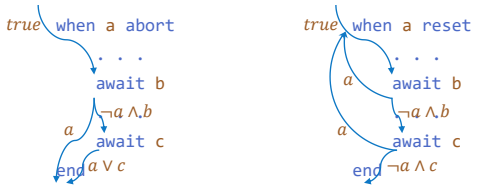
```
@[EntryPoint]
activity main()()
  var a: int32
  var b: int32
  var c: int32
  cobegin
    repeat
      await true
      a = a + 2
      c = b - a
    end
  with
    repeat
      await true
      b = 2 * (a + 1)
    end
  end
end
```




```
uint32_t main (int32_t *a, int32_t *b, int32_t *c, uint32_t *pc_1,
               uint32_t *pc_3, uint32_t *pc_2) {
  if ( *pc_1 == 2 ) {
    *a = 0;  // init
    *b = 0;
    *c = 0;
    *pc_2 = 7;  // enter branches and terminate step
    *pc_3 = 9;
    *pc_1 = 18;
  }
  if ( *pc_2 == 6 ) {  // left branch
    *a = (*a + 2);
    *pc_2 = 12;  // remember there is more to do
  }
  if ( *pc_3 == 8 ) {  // right branch
    *b = (2 * (*a + 1));
    *pc_3 = 9;  // terminate right step
  }
  if ( *pc_2 == 12 ) {  // left branch
    *c = (*b - *a);
    *pc_2 = 7;  // now terminate left step
  }
  _BLECH_SWITCH_TO_NEXTSTEP(*pc_2);  // bit-shifting magic
  _BLECH_SWITCH_TO_NEXTSTEP(*pc_3);
  _BLECH_SWITCH_TO_NEXTSTEP(*pc_1);
  return *pc_1;  // 0 means no more reaction steps to do
}
```

Blech
Stopping a behaviour

```
/// Keep blinking until the user presses button 1
activity Locked (pressedOne: bool) ()
    when pressedOne abort
        run Blink()
    end
end
```



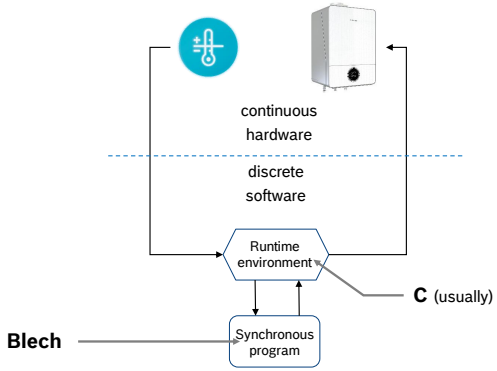
BOSCH

C interoperability
Calling Blech from a runtime

```
/* Main */

int main(int argc, const char * argv[])
{
    /* Create and initialize environment. */
    // …
    /* Initialize blech. */
    blc_blech_acc_init();

    /* Sense, control, act loop */
    while (1) {

        /* Get and adapt sensor input from environment. */
        env_input_state_t env_input_state = env_read(env);
        // …

        /* Run control reaction. */
        blc_blech_acc_tick(output_state.otherSpeed,
                           &output_state.egoSpeed,
                           &output_state.distance);

        /* Act on environment. */
        int hasCrashed = env_draw(env, &output_state);
        // …

        /* Wait for next tick.*/
        usleep(update_frequency);
    }

    /* Destroy environment. */
    env_destroy(env);

    return 0;
}
```

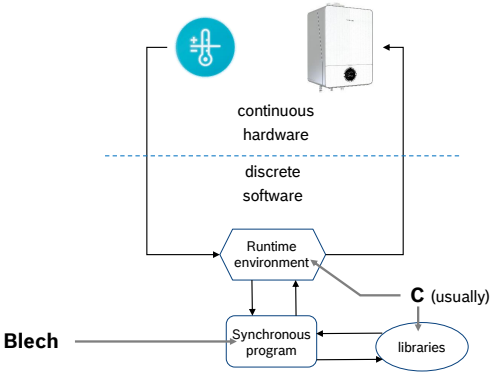

BOSCH

Abstract view of a reactive system
Where do we use a synchronous language?



BOSCH

Abstract view of a reactive system
Where do we use a synchronous language?



BOSCH

C interoperability
External constants

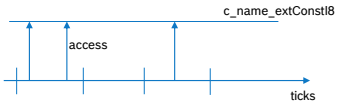
C

```
#define c_name_extConstI8 8
```

Blech

```
@[CConst(binding="c_name_extConstI8",
         header="my_externals.h")]
extern const extConstI8: int32
```

assumption
is constant throughout the whole runtime



usage

```
function f ()
    let testI8 = extConstI8
    // ...
end
```


C interoperability
External volatile read-only memory

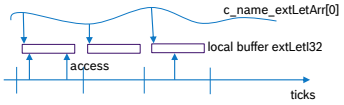
C

```
int c_name_extLetArr[8];
```

Blech

```
activity B ()
    @[CInput(binding="c_name_extLetArr[0]",
             header="my_externals.h")]
    extern let extLetI32: int32
    ...
end
```

assumption
is volatile



usage (multiple concurrent instances of B may run)

```
cobegin
    run B  ()
with
    run B  ()
end
```


C interoperability
External volatile read-write memory

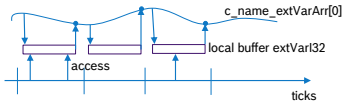
C

```
int c_name_extVarArr[8];
```

Blech

```
activity B ()
    @[COutput(binding="c_name_extVarArr[0]",
              header="my_externals.h")]
    extern var extVarI32: int32
    ...
end
```

assumption
is volatile



usage (B is a singleton now)

```
cobegin
    run B  ()
with
    run B  ()
end
```

error!

C interoperability
External (singleton) functions

C

```
uint8_t NRF24L01_spiIsReady (void)
{
    return (HAL_SPI_GetState(nrf24l01_init.hspi)
            == HAL_SPI_STATE_READY) ? 1 : 0;
}
```

Blech

```
@[CFunction(binding = "NRF24L01_spiIsReady",
            header = "nrf24l01.h")]
extern singleton function spiIsReady () returns bool
```

assumption
singleton:
- function either reads a volatile value
- or has a side-effect on the environment

not singleton:
- re-entrant, side-effect free function

usage (spiIsReady is declared to be a singleton)

```
cobegin
    await spiIsReady()
with
    await spiIsReady()
end
```

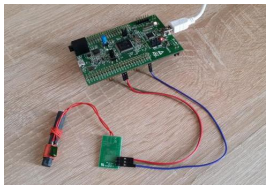
error!

Blech

Find all details on the language as it is currently implemented at
https://www.blech-lang.org/docs/user-manual/

If you find any mistakes or lack of clarity, please do notify us via Github issues.

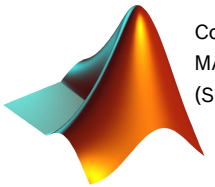
Application examples



DCF 77 signal decoding
bare metal

“Virtual lock”
FreeRTOS + Mita

Homework: ACC
Linux OS + ncurses



Controller development
MATLAB/Simulink
(S-function)

Overview

- Today’s speaker
- Why is synchronous programming interesting for Bosch?
- Design goals
- Blech – as of now
- **Application examples**
- Outlook on planned features
- Additional remarks

Overview

- Today’s speaker
- Why is synchronous programming interesting for Bosch?
- Design goals
- Blech – as of now
- Application examples
- **Outlook on planned features**
- Additional remarks

Outlook on planned features
What else should be possible with Blech?

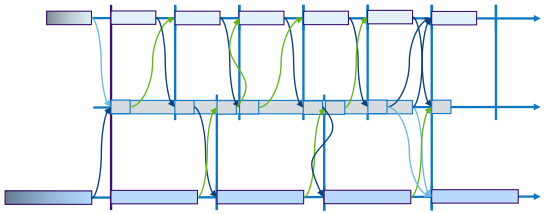
Mechanisms
- Parallel programming with multiple clocks
- Event communication using signals

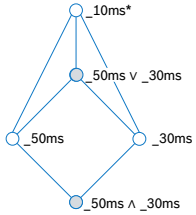
Software Engineering
- Module system
- Immutable references

Safety
- Physical dimensions
- Safe code generation

Mechanisms
Parallel programming with multiple clocks

- Communicating tasks must have related clocks
- Communication is done by sampling according to logical execution time
- Deterministic, consistent, compositional, real-time capable





Mechanisms
Communicating events with signals

```
activity Signalling()
    var finished: signal

    cobegin
        run anActivity()
        emit finished
    with
        repeat
            ...
            await true
        until finished end
        ...
    end
end
```

Signal
- Presence flag
- Optional payload
- Only present in emitting time step
- Automatically absent after reaction

Software engineering
Module system

- Decompose code into separately compiled units: “modules” (do not confuse with Esterel modules!)
- Modules must export types, activities or functions that should be used by their clients (API, information hiding)
- Interfaces must take causality information into account
- Module system translates names to unique C identifiers (everything is globally visible in C)

Safety
Physical dimensions

```
unit m
unit s

var length: float32[m]
var duration: float32[s]

length = 2 * length // ok
length = 2 + length // error!

let speed = length / duration // ok
let nonsense = length + duration // error
```

- The physical dimension are part of the data type
- Machine data types prevent arithmetic operations on incompatible types
- Physical dimensions prevent arithmetic operations which do not make sense
  (cf. homework code)

Overview

- Today's speaker
- Why is synchronous programming interesting for Bosch?
- Design goals
- Blech – as of now
- Application examples
- Outlook on planned features
- **Additional remarks**

Safety
Safe code generation

```
let a: [7]float32 = {...}
...
let x = a[i] // ok, provided i >= 0, i <= 6
```

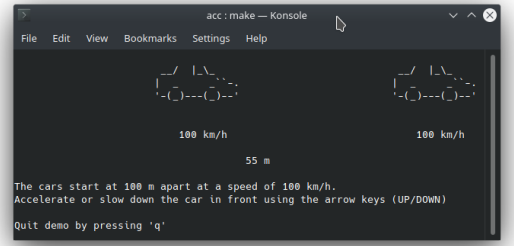
Debug code generation

```
float x;
if(i >= 0 && i <= 6) {
  x = a[i];
} else {
  haltWithDebugInfo();
}
```

Release code generation

```
float x;
if(i >= 0) {
  if (i <= 6) {
    x = a[i];
  } else {
    x = a[6];
  }
} else {
  x = a[0];
}
```


Homework
Adaptive Cruise Control

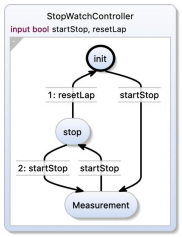


Bachelor / Master Thesis
Extraction of mode diagrams from Blech

Get in touch with Prof. von Hanxleden

```
activity StopWatchController (startStop: bool, resetLap: bool)
                             (display: Display)
    var totalTime: int32
    var lastLap: int32
    repeat
        totalTime = 0     // State init
        lastLap = 0
        writeTicksToDisplay(totalTime)(display)
        await startStop   // Transition init -> run
        repeat
            cobegin weak
                await startStop
            with weak
                run Measurement(resetLap)
                               (totalTime, lastLap, display)
            end
            // State stop, show total time and wait
            writeTicksToDisplay(totalTime)(display)
            await startStop or resetLap
            // Run again if only startStop was pressed
        until resetLap end // Back to init if
    end                    // resetLap was pressed
end
```

⇒



BOSCH

Where do I get Blech?
or how do I participate?

All info is available at www.blech-lang.org

Blech is **open source**! Driven by Bosch CR.

- Try Blech right now, start with tutorials and other examples. Why not write a blog post about your experience?
- Participate in discussions and give feedback on language design
- Actively shape Blech by contributing to the compiler, tooling or documentation
- Let's collaborate on product software, an evaluation prototype, a student thesis or internship
- We happily give a talk for your developers or managers or organise a hands-on tutorial
- The Blech team is open for ideas and discussions

BOSCH

Where do I get Blech?
or how do I participate?

Get in touch with us:

Friedrich.Gretz@de.bosch.com
Franz-Josef.Grosch@de.bosch.com

BOSCH