Introduction to ApplicationCore.

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MicroTCA Workshop - Tutorial “Introduction to ChimeraTK”

2017-12-05

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- DOOCS example:
  - Client $\xrightarrow{\text{write via RPC}}$ Server
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- Of course one has to decide for one implementation, but no fundamental difference in the application

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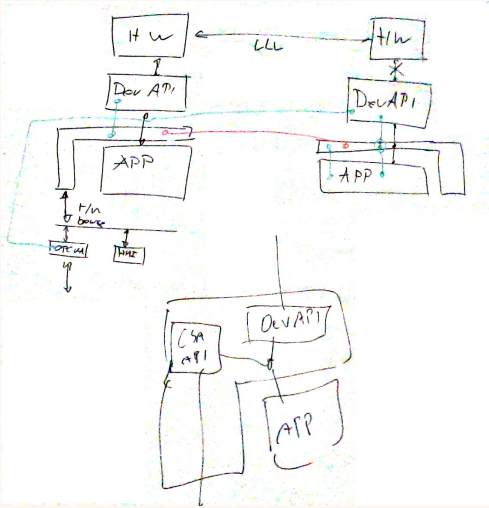
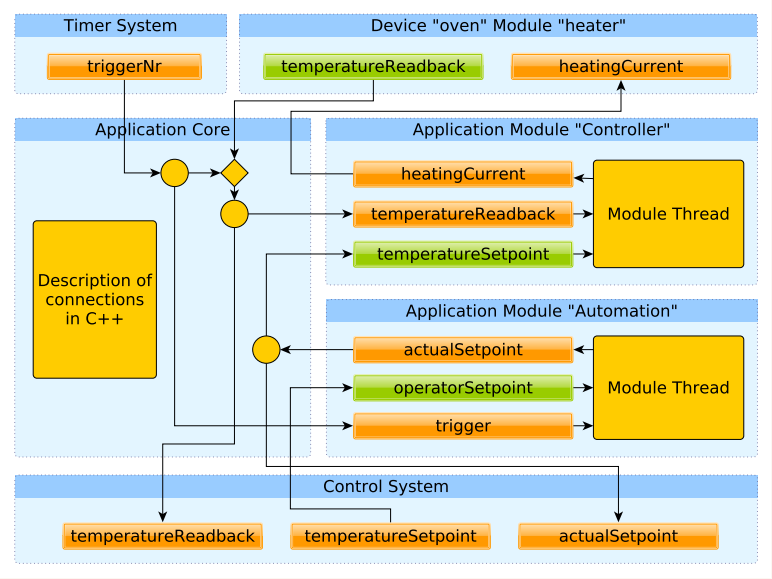


The structure of ApplicationCore



Central ideas for ApplicationCore

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- Encourage modular applications ($\rightarrow$ conceptional abstraction)
- Clean and simple interface, avoid boiler plate code as much as C++11 allows
- Avoid the need for user callback functions (excessive use makes code unreadable)
- Allow publishing a device register into the control system with a single code line

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  - Example: printer library drawing line on vector plotters and pixel printers
  - This is a difficult one! Often not possible on level of entire applications
  - Instead: break down application into abstract parts, combine them with little code
- Conceptional abstraction usualy involves also API abstraction
- Both improve code quality a lot!

Short refresh of C++ 11

- Default arguments to member constructors with braces

```
struct SomeClass {
  std::string myText{"Hello World"};
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struct SomeClass {
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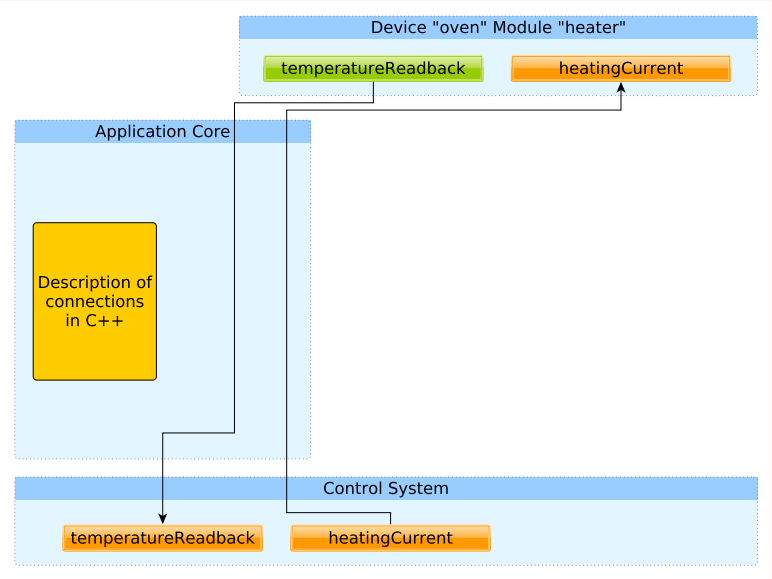
```

- Brace-initialisers when passing arguments

```
void someFunction(std::vector<int> values);
void main() {
  someFunction({1, 42, 33});
}
```

Direct access to device registers



Define the application (idealised code)

```
struct ExampleApp : public ctk::Application {



    ctk::DeviceModule heater{"oven","heater"};

    ctk::ControlSystemModule cs{"Bakery"};

    void defineConnections();
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ExampleApp theExampleApp;
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Description of connections (idealised code)

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void ExampleApp::defineConnections() {




    cs("heatingCurrent") >> heater("heatingCurrent");
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- Neither DeviceModule nor ControlSystemModule define their variable types
- DeviceAccess allows to read a register as any type
- ControlSystemAdater variables are created on-the-fly
- We need to specify the type and array length here!

Description of connections (idealised code)

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void ExampleApp::defineConnections() {




    cs("heatingCurrent", typeid(int), 1) >> heater("heatingCurrent");
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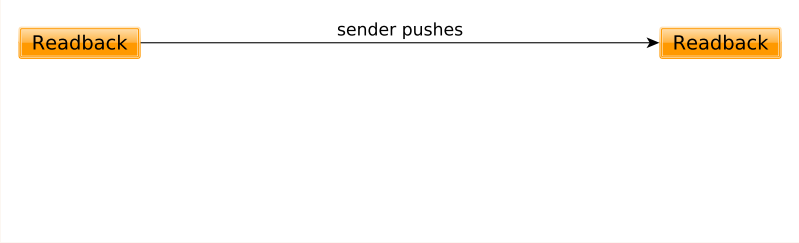
Excursus: Update modes

- Generalise the client/server concept



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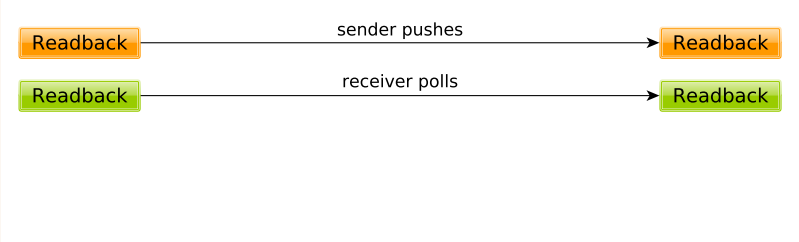

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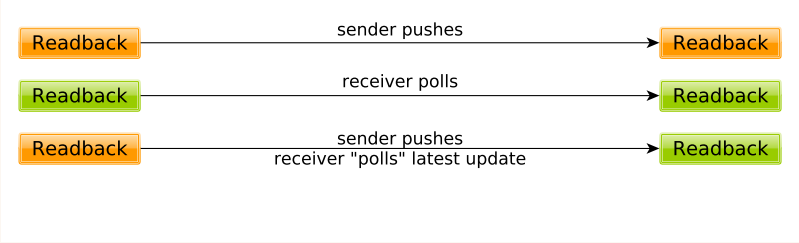

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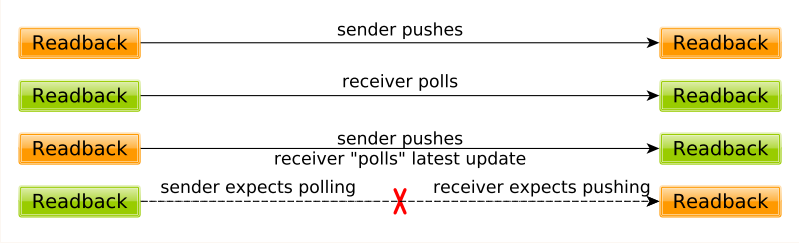
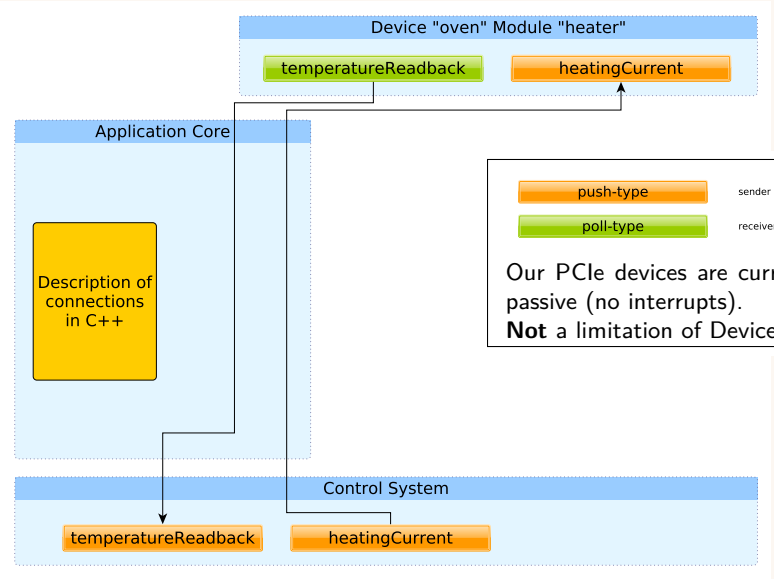


Introduction of triggers



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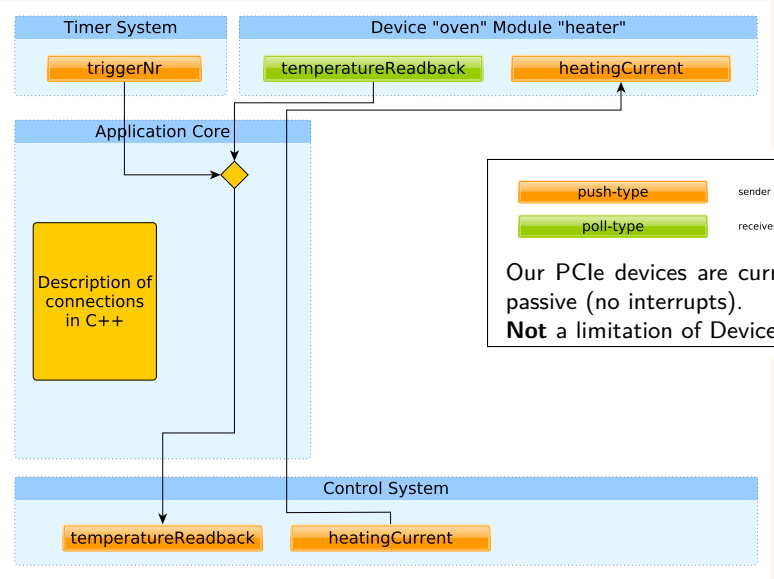


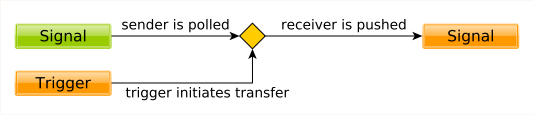
push-type — sender active, receiver passive

poll-type — receiver active, sender passive

Our PCIe devices are currently always passive (no interrupts).
Not a limitation of DeviceAccess!

Introduction of triggers

- When connecting a poll-type output (e.g. a PCIe register) with a push-type input, a trigger for the transfer is needed



- Any push-type variable can act as a trigger, its value will be ignored
- It can come from a device, another ApplicationModule or even the ControlSystemAdapter

Description of connections (actual code!)

```
void ExampleApp::defineConnections() {
    mtca4u::setDMapFilePath("devices.dmap");

    auto triggerNr = timer("triggerNr", typeid(int), 1, ctk::UpdateMode::push);

    cs("heatingCurrent", typeid(int), 1) >> heater("heatingCurrent");
    heater("temperatureReadback", typeid(double), 1) [ triggerNr ]
        >> cs("temperatureReadback");
}
```

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}
```

- DeviceAccess variables are by default poll-type
- Need to change this to push-type

Define the application (actual code!)

```
struct ExampleApp : public ctk::Application {
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No main() function shall be defined, it is coming from the adapter!

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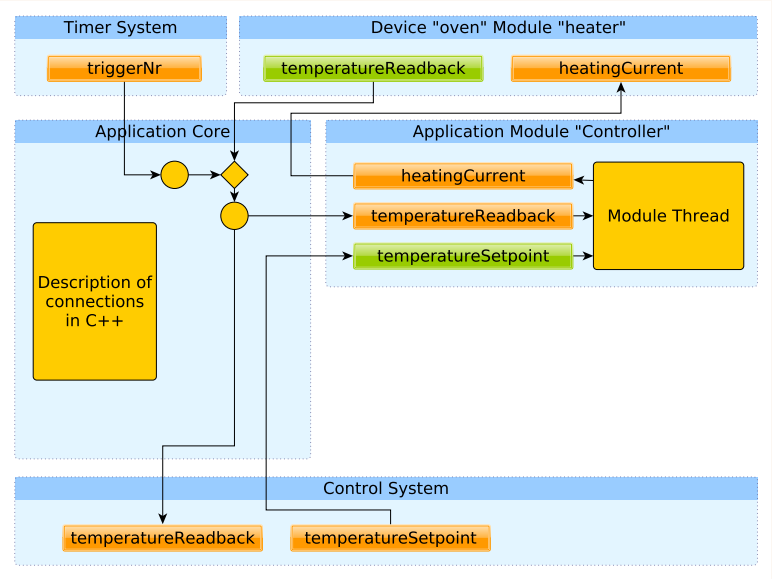
Live demo now! (01)

Make the application smarter!

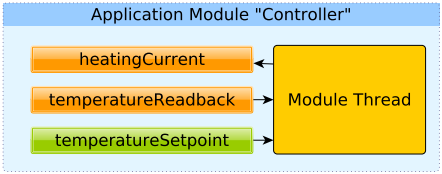


Add an ApplicationModule (idealised code)

```
struct Controller : public ctk::ApplicationModule {

    ctk::ScalarInput<double> sp{"sp", "degC", "Description"};
    ctk::ScalarInput<double> rb{"rb", "degC", "..."};
    ctk::ScalarOutput<double> cur{"cur", "mA", "..."};

    void mainLoop() {
      const double gain = 100.0;
      while(true) {
        rb.read();
        sp.read();
        cur = gain * (sp - rb);
        cur.write();
      }
    }
};
```



Add an ApplicationModule (towards actual code - step 1)

```
struct Controller : public ctk::ApplicationModule {

    ctk::ScalarInput<double> sp{this, "sp", "degC", "Description"};
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    }
};
```

Need to know the owner!

Application Module (towards actual code - step 2)

```
struct Controller : public ctk::ApplicationModule {
    using ctk::ApplicationModule::ApplicationModule;   ⟵ Inherit constructor
    ctk::ScalarInput<double> sp{this, "sp", "degC", "Description"};
    ctk::ScalarInput<double> rb{this, "rb", "degC", "..."};
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Application Module (actual code!)

```
struct Controller : public ctk::ApplicationModule {
    using ctk::ApplicationModule::ApplicationModule;
    ctk::ScalarPollInput<double> sp{this, "sp", "degC", "Description"};
    ctk::ScalarPushInput<double> rb{this, "rb", "degC", "..."};
    ctk::ScalarOutput<double> cur{this, "cur", "mA", "..."};
                    Define the update mode. Outputs are always push-type.
    void mainLoop() {
      const double gain = 100.0;
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        rb.read();    // waits until update arrives
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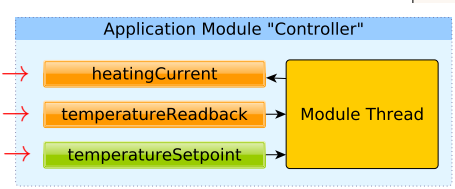

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```

Interface from DeviceAccess

- ScalarPollInput / ScalarPushInput / ScalarOutput
  ⇒ ScalarRegisterAccessor
- ArrayPollInput / ArrayPushInput / ArrayOutput
  ⇒ OneDRegisterAccessor

```
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Application Module (actual code!)

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Interface from DeviceAccess

- ScalarPollInput / ScalarPushInput / ScalarOutput
  ⇒ ScalarRegisterAccessor
- ArrayPollInput / ArrayPushInput / ArrayOutput
  ⇒ OneDRegisterAccessor
- Actual inheritance!
- Only adds *inversion of control*

```
};
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Application Module (actual code!)

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    }
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Live demo now! (02)

Definition of connections for live demo 02

```
void ExampleApp::defineConnections() {
    mtca4u::setDMapFilePath("devices.dmap");

    auto triggerNr = timer("triggerNr", typeid(int), 1, ctk::UpdateMode::push);

    cs("temperatureSetpoint") >> controller.temperatureSetpoint;
    controller.heatingCurrent >> heater("heatingCurrent");
    heater("temperatureReadback") [ triggerNr ] >> controller.temperatureReadback
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  - Keep a variable out an ApplicationModule if it doesn't belong there!
    Don't place `supplyVoltages` into the `Controller` module
  - If an ApplicationModule acts upon change of an input, make that clear by using a push-type input
- NB: Application-wide periodic triggers are like the cycle time in PLCs

Let's add some monitoring!

```
void ExampleApp::defineConnections() {
    mtca4u::setDMapFilePath("devices.dmap");

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    controller.heatingCurrent >> heater("heatingCurrent");
    heater("temperatureReadback") [ triggerNr ] >> controller.temperatureReadback
        >> cs("temperatureReadback");

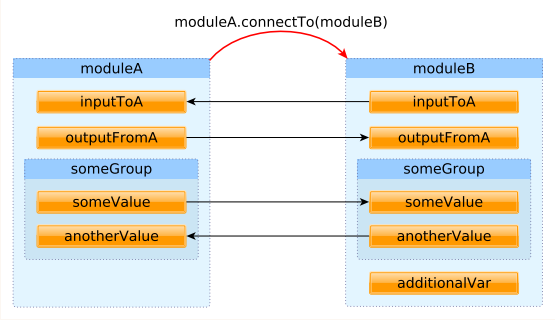
    heater("supplyVoltages", typeid(int), 4) [ triggerNr ] >> cs("supplyVoltages");
    triggerNr >> cs("triggerNr");


}
```

Live demo now! (03)

Shortcut: do many connections at a time with connectTo()

- Connect all variables of module with variables of same name in other module
- Works recursively (variables can be grouped with `VariableGroup`)



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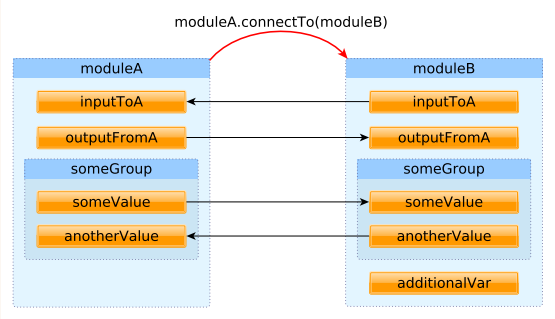

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- Works recursively (variables can be grouped with `VariableGroup`)
- Does not care about additional variables in the target module
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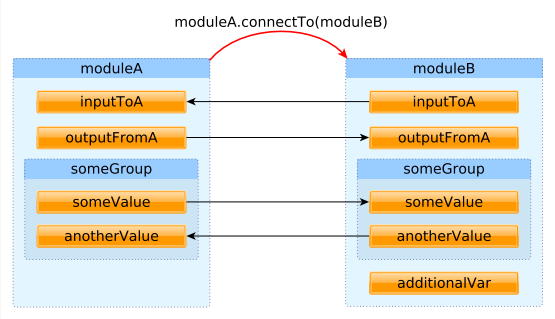
- Works nicely with ControlSystemModule which creates variables on demand



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    controller.heatingCurrent >> heater("heatingCurrent");
    heater("temperatureReadback") [ triggerNr ] >> controller.temperatureReadback
        >> cs("temperatureReadback");

    heater("supplyVoltages", typeid(int), 4) [ triggerNr ] >> cs("supplyVoltages");
    triggerNr >> cs("triggerNr");


}
```

Shortcut: do many connections at a time with connectTo()

```
void ExampleApp::defineConnections() {
    mtca4u::setDMapFilePath("devices.dmap");

    auto triggerNr = timer("triggerNr", typeid(int), 1, ctk::UpdateMode::push);

    cs("temperatureSetpoint") >> controller.temperatureSetpoint;
    controller.heatingCurrent >> heater("heatingCurrent");
    heater("temperatureReadback") [ triggerNr ] >> controller.temperatureReadback;
    controller.temperatureReadback >> cs("temperatureReadback");

    heater("supplyVoltages", typeid(int), 4) [ triggerNr ] >> cs("supplyVoltages");
    triggerNr >> cs("triggerNr");


}
```

Shortcut: do many connections at a time with connectTo()

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void ExampleApp::defineConnections() {
    mtca4u::setDMapFilePath("devices.dmap");

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    controller.heatingCurrent >> heater("heatingCurrent");
    heater("temperatureReadback") [ triggerNr ] >> controller.temperatureReadback;
//  controller.temperatureReadback >> cs("temperatureReadback");

    heater("supplyVoltages", typeid(int), 4) [ triggerNr ] >> cs("supplyVoltages");
    triggerNr >> cs("triggerNr");

    controller.connectTo(cs);   // could connect arbitrary number of variables
}
```

Live demo now! (04)

Tags

- Variables can have any number of tags attachted
- A tag is any alpha-numeric string (no spaces)
- Not visible outside the application
- Can be used to search for a subset of variables

Tags

```
// ApplicationModule "Controller":
ctk::ScalarPollInput<double> temperatureSetpoint{..., {"CS"}};
ctk::ScalarOutput<double> heatingCurrent{..., {"HEATER"}};
ctk::ScalarPushInput<double> temperatureReadback{..., {"CS", "HEATER"}};

// defineConnections():
controller.findTag("HEATER").connectTo(heater, triggerNr);
controller.findTag("CS").connectTo(cs);
```

Tags

```
    // ApplicationModule "Controller":
    ctk::ScalarPollInput<double> temperatureSetpoint{..., {"CS"}};
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    controller.findTag("CS").connectTo(cs);
```

```
/**
 * Connect the entire module into another module. [...]
 *
 * If an optional trigger node is specified, this trigger node is applied to all
 * poll-type output variables of the target module, which are being connected during
 * this operation, if the corresponding variable in this module is push-type.
 */
void Module::connectTo(const Module &target, VariableNetworkNode trigger={}) const;
```

Tags

```
// ApplicationModule "Controller":
ctk::ScalarPollInput<double> temperatureSetpoint{..., {"CS"}};
ctk::ScalarOutput<double> heatingCurrent{..., {"HEATER"}};
ctk::ScalarPushInput<double> temperatureReadback{..., {"CS", "HEATER"}};

// defineConnections():
controller.findTag("HEATER").connectTo(heater, triggerNr);
controller.findTag("CS").connectTo(cs);
```

The order matters!

- The oder of `connectTo()` statements may matter
- Device and control system variables decide their direction from the context
- Swapping the two statements would feed `temperatureReadback` from the control system and pass a copy to the device

Tags

```
// ApplicationModule "Controller":
ctk::ScalarPollInput<double> temperatureSetpoint{..., {"CS"}};
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// defineConnections():
controller.findTag("HEATER").connectTo(heater, triggerNr);
controller.findTag("CS").connectTo(cs);
```

Live demo now! (05)

Pipes

- A pipe is a standard ApplicationModule simply passing on a variable
- Very useful for direct connections between devices and control system

```
// Application:
ctk::ArrayPipe<int> supplyVoltages{ this, "supplyVoltages", "mV", 4, "...",
                                    {"HEATER"}, {"CS"} };
//                            input tags ^^        ^^ output tags

// defineConnections():
controller.findTag("HEATER").connectTo(heater, triggerNr);
controller.findTag("CS").connectTo(cs);
supplyVoltages.findTag("HEATER").connectTo(heater, triggerNr);
supplyVoltages.findTag("CS").connectTo(cs);
```

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// defineConnections() smarter:
findTag("HEATER").connectTo(heater, triggerNr);
findTag("CS").connectTo(cs);
```

Live demo now! (06)

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// Application:
ctk::ArrayPipe<int> supplyVoltages{ this, "supplyVoltages", "mV", 4, "...",
                                    {"HEATER"}, {"CS"} };
//                            input tags ^^        ^^ output tags

// defineConnections() smarter:
findTag("HEATER").flatten().connectTo(heater, triggerNr);
findTag("CS").connectTo(cs);
```

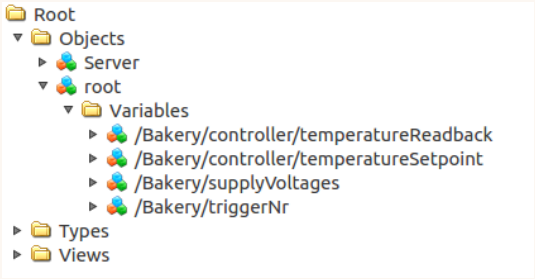
Pipes

flatten()

- Eliminates all hierarchies (just for the current operation)
- Common use case: device with flat hierarchy but register access scattered over many modules

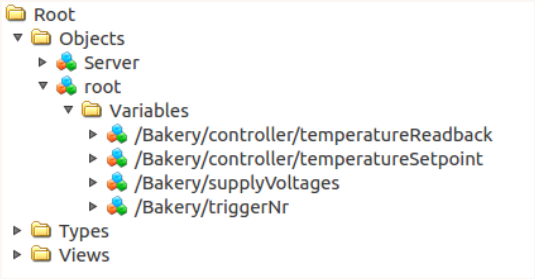
```
// defineConnections() smarter:
findTag("HEATER").flatten().connectTo(heater, triggerNr);
findTag("CS").connectTo(cs);
```

Information model



- Model already improved a bit by introducing the “controller” directory
- Still, a bakery does not has a controller - the oven has it!

Information model



- Model already improved a bit by introducing the “controller” directory
- Still, a bakery does not has a controller - the oven has it!
- Assuming this application represents an entire bakery, we shall introduce the oven an entity in both the source code and the control system hierarchy
- In other words: pick the right level of conceptional abstraction for each part of the application

Group modules

```
struct Oven : public ctk::ModuleGroup {
    using ctk::ModuleGroup::ModuleGroup;

    Controller controller{this, "controller", "Proportional controller..."};
    ctk::ArrayPipe<int> supplyVoltages{ this, "supplyVoltages", "mV", 4, "...",
                                        {"HEATER"}, {"CS"} };

};
```

Live demo now! (07)

Controlling multiple ovens

```
// Application:
std::vector<Oven> ovens;
std::vector<ctk::DeviceModule> heaters;

// defineConnections():
for(size_t i=0; i<2; ++i) {
  ovens.emplace_back(this, "oven"+std::to_string(i), "Oven "+std::to_string(i));
  heaters.emplace_back("oven"+std::to_string(i),"heater");

  ovens[i].findTag("HEATER").flatten().connectTo(heaters[i], triggerNr);
}
```

Live demo now! (08)

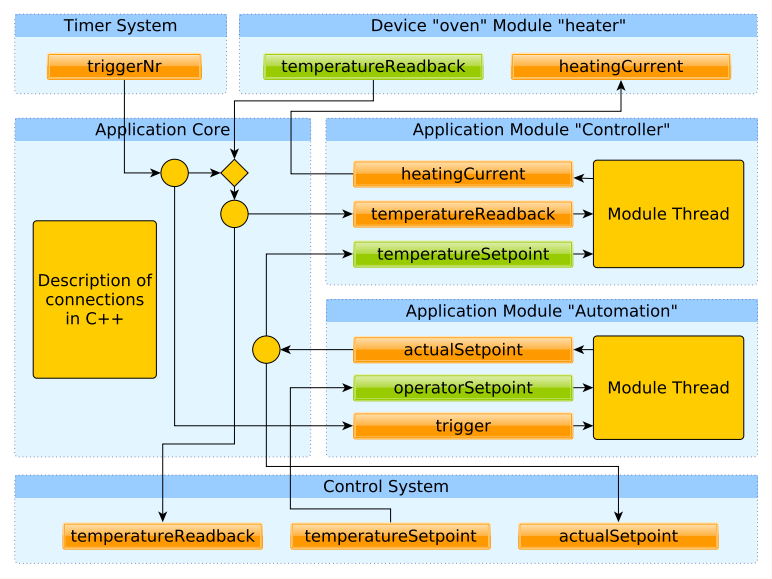
More possibilities for improving the information model

- `excludeTag()` is the opposite of `findTag()`
- `findTag()` and `excludeTag()` both support regular expressions
- Any level in the hierarchy might be "eliminated" if introduced only for technical reasons (e.g. need for `readAll()` on a `VariableGroup`), see `Module::setEliminateHierarchy()`
- In case of doubt: use `Module::dump()` or the result of `findTag()` etc., e.g.:

```
ovens[0].dump();
findTag("CS").dump();
```

- Or use `Module::dumpGraph()` to generate GraphViz dot code

Multiple modules



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  - Improves application structure (easier conceptual abstraction, reusing code)

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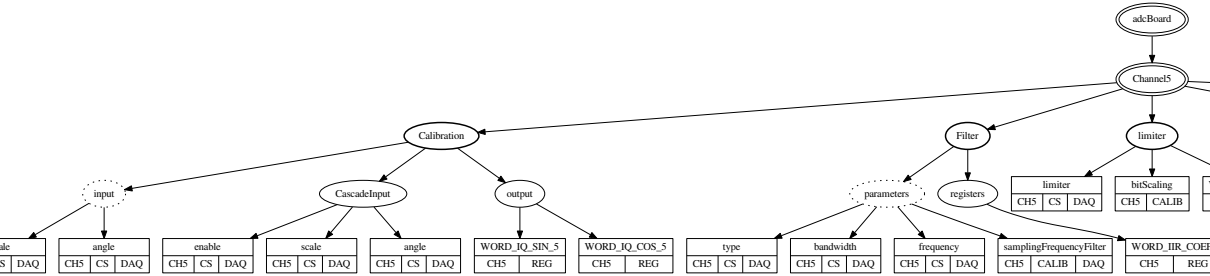
- Message-based: values of variables are passed to other modules
- Lock-free: no dead locks can occur
- Futures: can effectively wait without using the cpu
- No mutexes: no non-concurrent code sections which would spoil scalability

Example: LLRF server module adcBoard, Channel 5 (partial)



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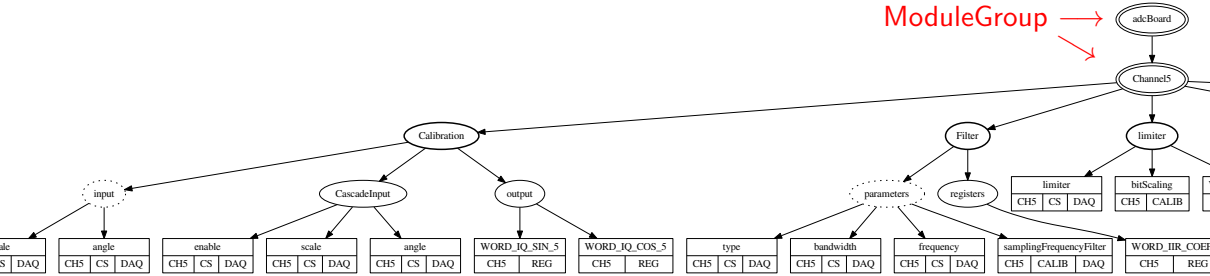

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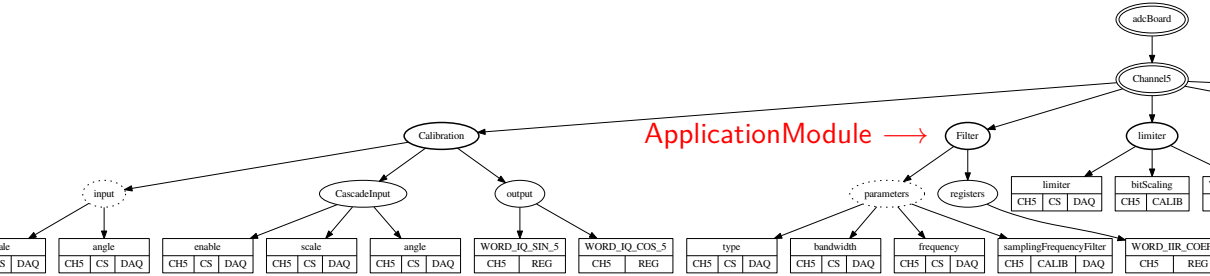

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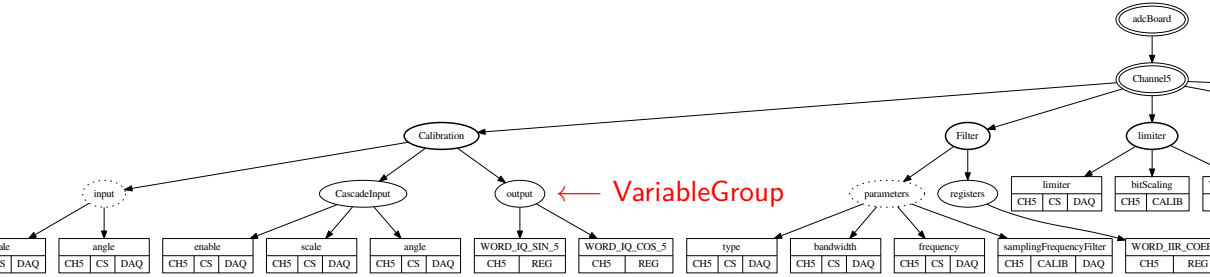

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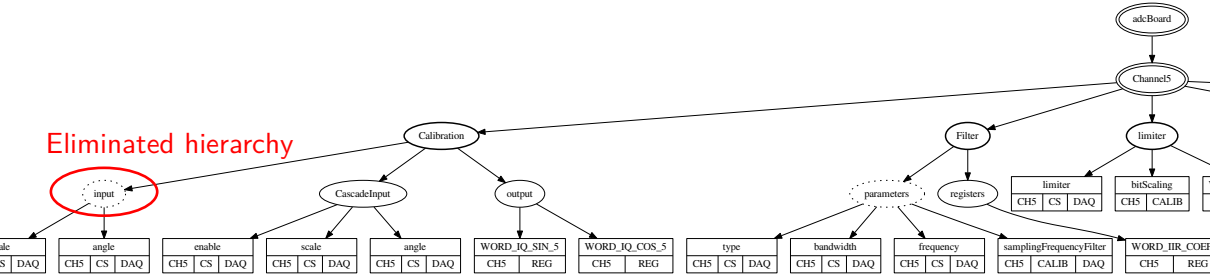

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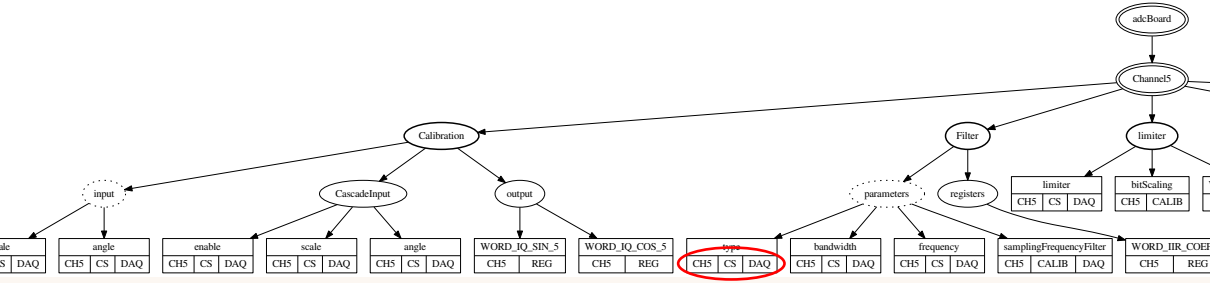

- Tag “CH5”: other modules also provide variables for Channel 5
- Tags “REG” and “CS”: device registers and control system variables
- Tag “CALIB”: global calibration values
- Tag “DAQ”: variables go into the internal DAQ system (if enabled)

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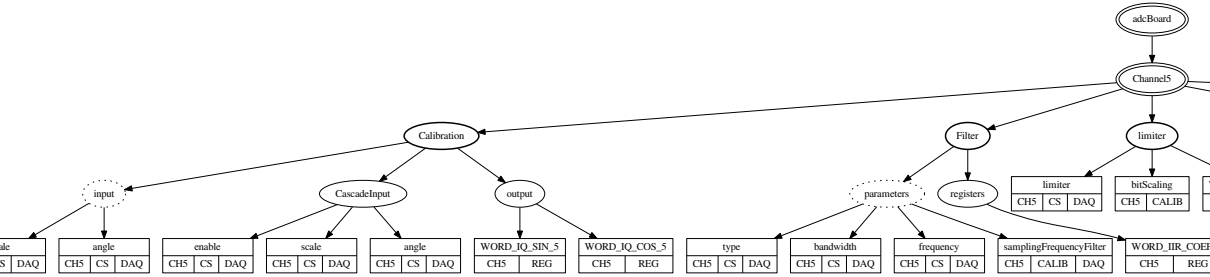

- For more details about the LLRF server, come to my poster: **ApplicationCore: A Framework for Modern Control Applications at the Example of a Facility Independent LLRF Server**