Problem definition:

- Over the last few years, there has been research into the cultivation technique known as “fogponics”, a high-intensity form of agriculture which benefits more from automation than any other.

- This project provides a management and control system for a fleet of fogponics units that can be extended to other use-cases.

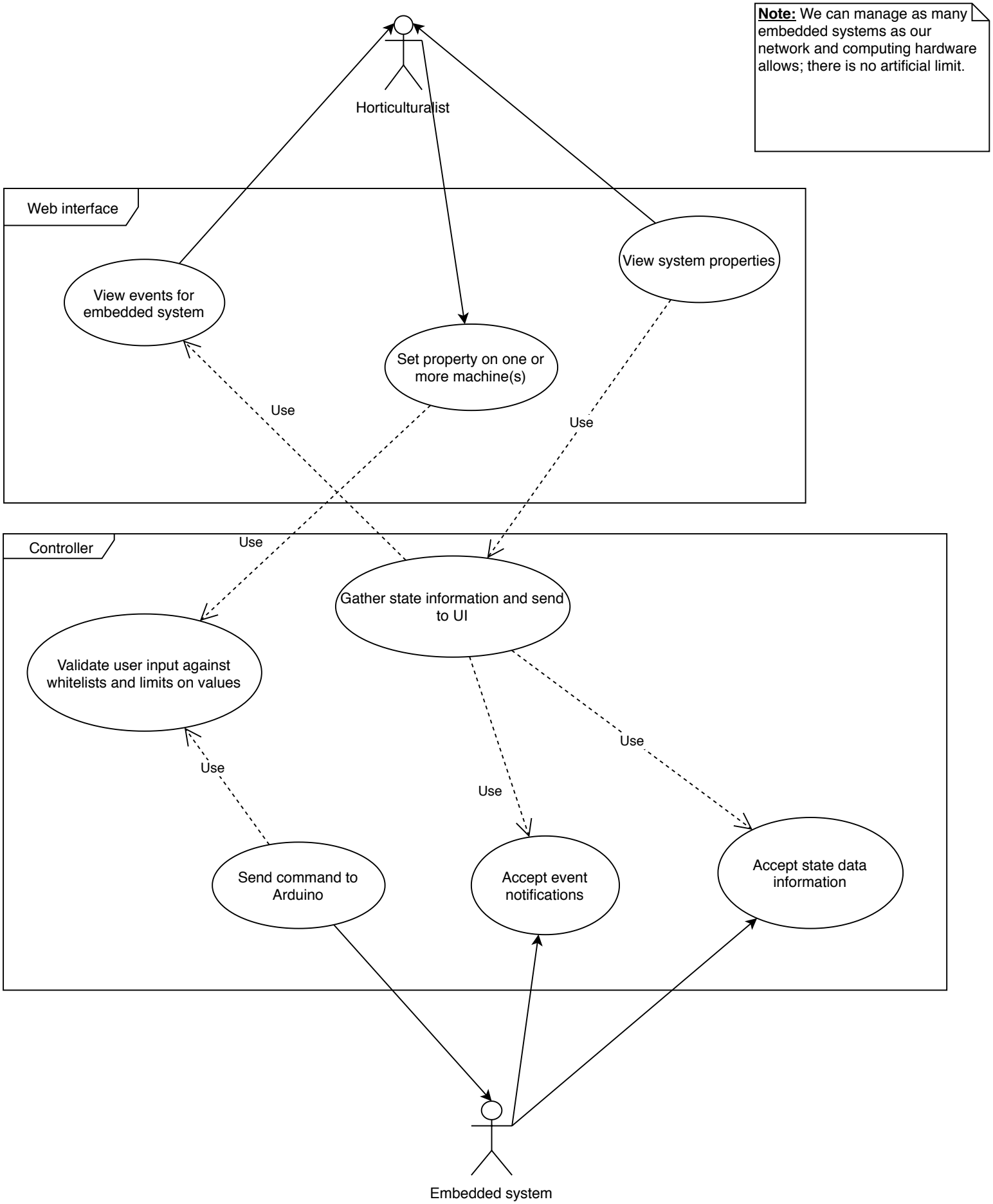
- This is in continuation of a project I have been running off and for half a year. The physical prototype is (mostly) built but lacks a control panel.

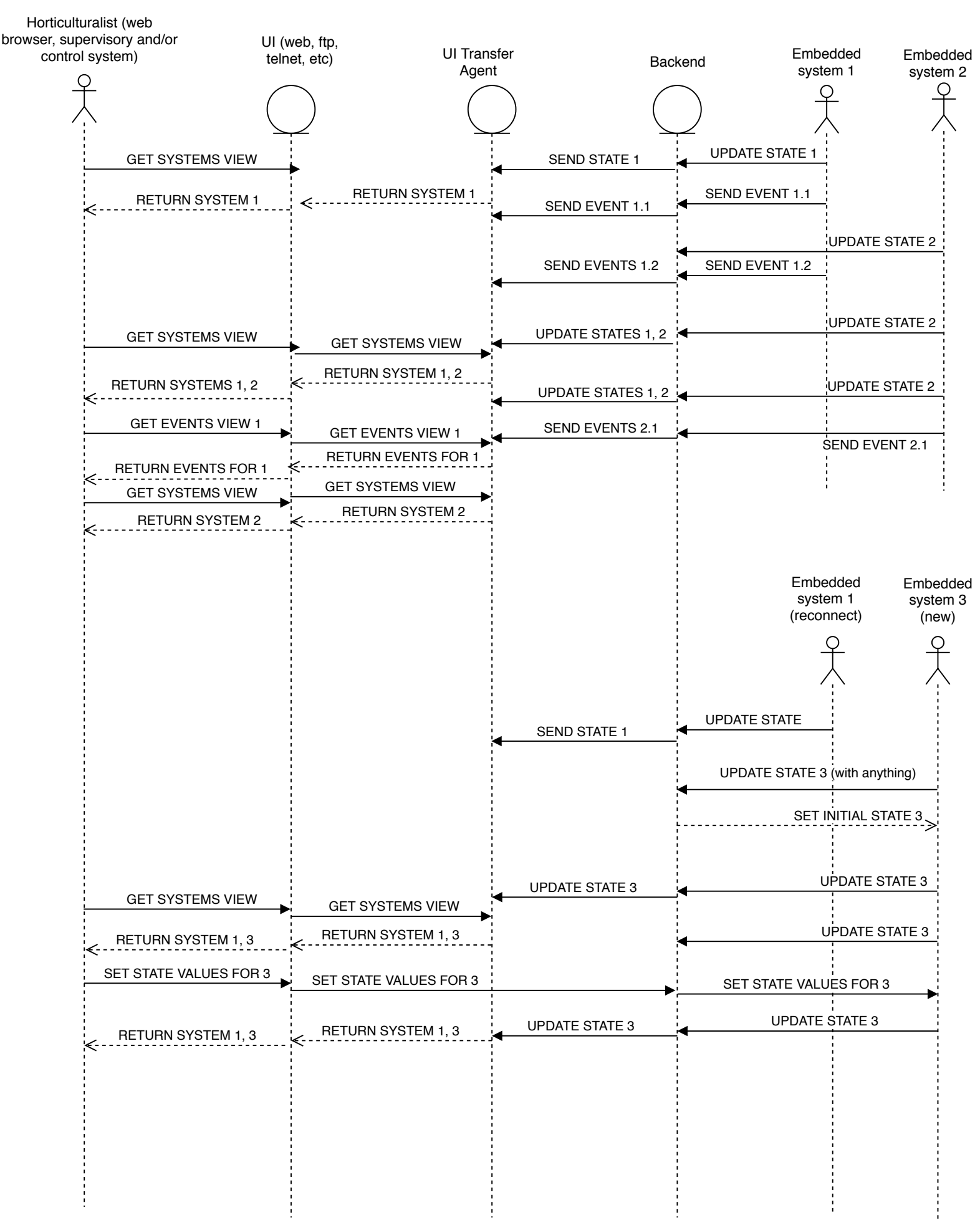
We got ourselves a control panel.

:)

Functional requirements:

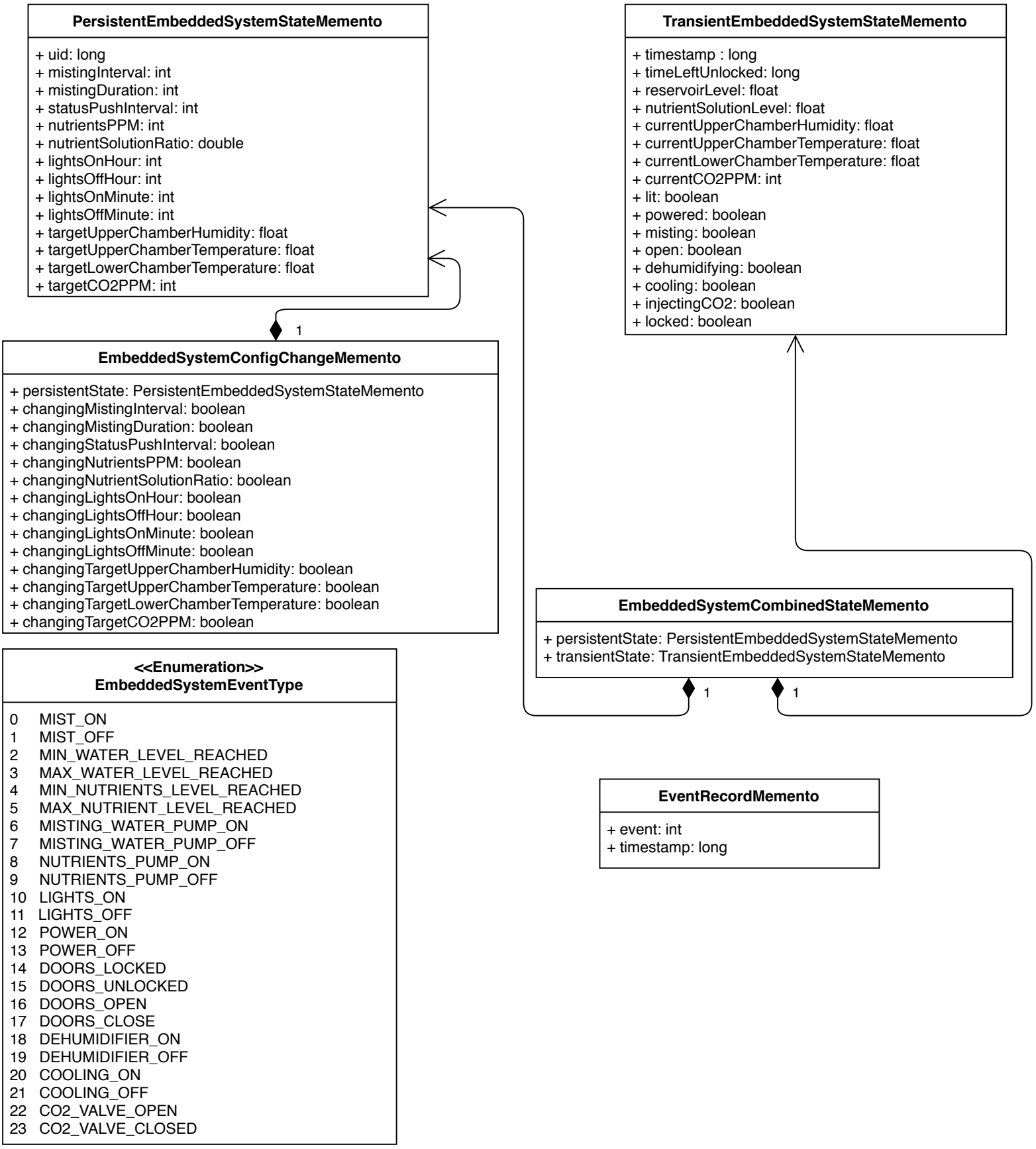
- We're building a basic control system for an IoT use-case.
- The control system gathers and updates the current state information of the embedded systems growing plants.
- It must also be able to maintain a list of recent events for perusal by the end-user.
- New systems are to be automatically given sane defaults and added to the system pool. The only user responsibility must be sourcing the embedded system with a unique 64-bit integer ID.
- The end-user must be able to change settings.
- These settings must be validated in order to correct against nonsense inputs.
- "Computer, set the rooting chamber to -273 degrees C…"
- The embedded system running the grow environments should do their its own validation as good engineering, but layers of safety protect against screwups downstream.
- In effect, it acts as an application firewall.
- That's basically it as far as *functional* requirements go.


Note: We can manage as many embedded systems as our network and computing hardware allows; there is no artificial limit.
Horticulturalist
Web interface
View events for embedded system
Set property on one or more machine(s)
View system properties
Use
Use
Use
Controller
Gather state information and send to UI
Validate user input against whitelists and limits on values
Use
Use
Use
Send command to Arduino
Accept event notifications
Accept state data information
Embedded system


Horticulturalist (web browser, supervisory and/or control system)
UI (web, ftp, telnet, etc)
UI Transfer Agent
Backend
Embedded system 1
Embedded system 2
GET SYSTEMS VIEW
SEND STATE 1
UPDATE STATE 1
RETURN SYSTEM 1
RETURN SYSTEM 1
SEND EVENT 1.1
SEND EVENT 1.1
UPDATE STATE 2
SEND EVENTS 1.2
SEND EVENT 1.2
UPDATE STATE 2
GET SYSTEMS VIEW
GET SYSTEMS VIEW
UPDATE STATES 1, 2
RETURN SYSTEM 1, 2
RETURN SYSTEMS 1, 2
UPDATE STATES 1, 2
UPDATE STATE 2
GET EVENTS VIEW 1
GET EVENTS VIEW 1
SEND EVENTS 2.1
SEND EVENT 2.1
RETURN EVENTS FOR 1
RETURN EVENTS FOR 1
GET SYSTEMS VIEW
GET SYSTEMS VIEW
RETURN SYSTEM 2
RETURN SYSTEM 2
Embedded system 1 (reconnect)
Embedded system 3 (new)
UPDATE STATE
SEND STATE 1
UPDATE STATE 3 (with anything)
SET INITIAL STATE 3
UPDATE STATE 3
UPDATE STATE 3
GET SYSTEMS VIEW
GET SYSTEMS VIEW
RETURN SYSTEM 1, 3
RETURN SYSTEM 1, 3
UPDATE STATE 3
SET STATE VALUES FOR 3
SET STATE VALUES FOR 3
SET STATE VALUES FOR 3
UPDATE STATE 3
RETURN SYSTEM 1, 3
RETURN SYSTEM 1, 3
UPDATE STATE 3

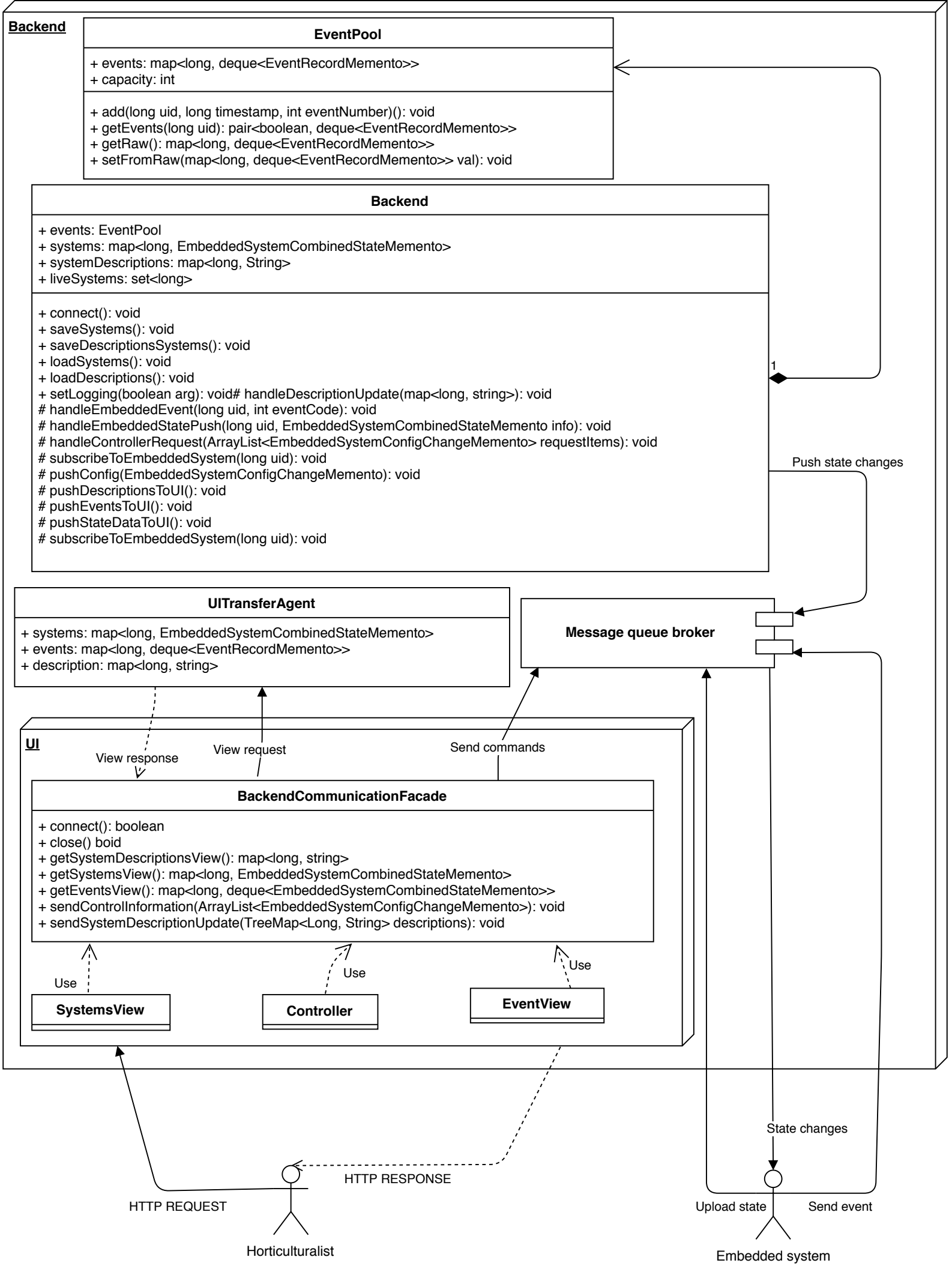
Design patterns:

- The main design pattern in use here is the memento pattern.
- Memento allows you to use state to represent logical items for recall when convenient.
- It is also really good for indicating your next intentions.
- Literally stands for “memory aid.”
- Also used in the web UI are builder patterns, but their use is perfunctory...
- Reusing code to write HTML tags to a page more neatly.
- Aside: I really wanted to keep it unix by using a simple command-line app, but we went that way instead and deep down I’m kinda glad I stepped out of my bubble.
- We also use a static factory method or two.
- However, they’re nothing too interesting as far as our use-case is concerned. They’re also completely perfunctory and don’t really warrant too much discussion.
- They’d be far more central for our purposes and worth talking about if we were writing a serializer, for example...


PersistentEmbeddedSystemStateMemento
+ uid: long
+ mistingInterval: int
+ mistingDuration: int
+ statusPushInterval: int
+ nutrientsPPM: int
+ nutrientSolutionRatio: double
+ lightsOnHour: int
+ lightsOffHour: int
+ lightsOnMinute: int
+ lightsOffMinute: int
+ targetUpperChamberHumidity: float
+ targetUpperChamberTemperature: float
+ targetLowerChamberTemperature: float
+ targetCO2PPM: int
TransientEmbeddedSystemStateMemento
+ timestamp : long
+ timeLeftUnlocked: long
+ reservoirLevel: float
+ nutrientSolutionLevel: float
+ currentUpperChamberHumidity: float
+ currentUpperChamberTemperature: float
+ currentLowerChamberTemperature: float
+ currentCO2PPM: int
+ lit: boolean
+ powered: boolean
+ misting: boolean
+ open: boolean
+ dehumidifying: boolean
+ cooling: boolean
+ injectingCO2: boolean
+ locked: boolean
1
EmbeddedSystemConfigChangeMemento
+ persistentState: PersistentEmbeddedSystemStateMemento
+ changingMistingInterval: boolean
+ changingMistingDuration: boolean
+ changingStatusPushInterval: boolean
+ changingNutrientsPPM: boolean
+ changingNutrientSolutionRatio: boolean
+ changingLightsOnHour: boolean
+ changingLightsOffHour: boolean
+ changingLightsOnMinute: boolean
+ changingLightsOffMinute: boolean
+ changingTargetUpperChamberHumidity: boolean
+ changingTargetUpperChamberTemperature: boolean
+ changingTargetLowerChamberTemperature: boolean
+ changingTargetCO2PPM: boolean
EmbeddedSystemCombinedStateMemento
+ persistentState: PersistentEmbeddedSystemStateMemento
+ transientState: TransientEmbeddedSystemStateMemento
1
1
<<Enumeration>>
EmbeddedSystemEventType
0 MIST_ON
1 MIST_OFF
2 MIN_WATER_LEVEL_REACHED
3 MAX_WATER_LEVEL_REACHED
4 MIN_NUTRIENTS_LEVEL_REACHED
5 MAX_NUTRIENT_LEVEL_REACHED
6 MISTING_WATER_PUMP_ON
7 MISTING_WATER_PUMP_OFF
8 NUTRIENTS_PUMP_ON
9 NUTRIENTS_PUMP_OFF
10 LIGHTS_ON
11 LIGHTS_OFF
12 POWER_ON
13 POWER_OFF
14 DOORS_LOCKED
15 DOORS_UNLOCKED
16 DOORS_OPEN
17 DOORS_CLOSE
18 DEHUMIDIFIER_ON
19 DEHUMIDIFIER_OFF
20 COOLING_ON
21 COOLING_OFF
22 CO2_VALVE_OPEN
23 CO2_VALVE_CLOSED
EventRecordMemento
+ event: int
+ timestamp: long

Model-Controller-View:

- Views are sent out the backend and into a separate utility that decouples data being sent out from the rest of the backend program; views talk to that program and don’t even talk about our backend.
- Commands and state changes are sent via MQTT. These represent the controls and the in-flight representation of the model, respectively.
- The web UI uses a custom Servlet as a controller that kicks up the MQTT client the very first time it runs.
- The views are gathered and formatted by custom tag classes invoked by an otherwise logic-free JSP page.
- This represents proper modern practices.


Backend
EventPool
+ events: map<long, deque<EventRecordMemento>>
+ capacity: int
+ add(long uid, long timestamp, int eventNumber)(): void
+ getEvents(long uid): pair<boolean, deque<EventRecordMemento>>
+ getRaw(): map<long, deque<EventRecordMemento>>
+ setFromRaw(map<long, deque<EventRecordMemento>> val): void
Backend
+ events: EventPool
+ systems: map<long, EmbeddedSystemCombinedStateMemento>
+ systemDescriptions: map<long, String>
+ liveSystems: set<long>
+ connect(): void
+ saveSystems(): void
+ saveDescriptionsSystems(): void
+ loadSystems(): void
+ loadDescriptions(): void
+ setLogging(boolean arg): void# handleDescriptionUpdate(map<long, string>): void
# handleEmbeddedEvent(long uid, int eventCode): void
# handleEmbeddedStatePush(long uid, EmbeddedSystemCombinedStateMemento info): void
# handleControllerRequest(ArrayList<EmbeddedSystemConfigChangeMemento> requestItems): void
# subscribeToEmbeddedSystem(long uid): void
# pushConfig(EmbeddedSystemConfigChangeMemento): void
# pushDescriptionsToUI(): void
# pushEventsToUI(): void
# pushStateDataToUI(): void
# subscribeToEmbeddedSystem(long uid): void
1
Push state changes
UITransferAgent
+ systems: map<long, EmbeddedSystemCombinedStateMemento>
+ events: map<long, deque<EventRecordMemento>>
+ description: map<long, string>
Message queue broker
UI
View response
View request
Send commands
BackendCommunicationFacade
+ connect(): boolean
+ close() boid
+ getSystemDescriptionsView(): map<long, string>
+ getSystemsView(): map<long, EmbeddedSystemCombinedStateMemento>
+ getEventsView(): map<long, deque<EmbeddedSystemCombinedStateMemento>>
+ sendControlInformation(ArrayList<EmbeddedSystemConfigChangeMemento>): void
+ sendSystemDescriptionUpdate(TreeMap<Long, String> descriptions): void
Use
Use
Use
SystemsView
Controller
EventView
State changes
HTTP RESPONSE
HTTP REQUEST
Upload state
Send event
Horticulturalist
Embedded system

How we store and transmit config changes:

```
public class
PersistentEmbeddedSystemStateMemento {
    private long uid;
    private int mistingInterval;
    private int mistingDuration;
    private int statusPushInterval;
    private int nutrientsPPM;
    private double nutrientSolutionRatio;
    private int lightsOnHour;
    private int lightsOffHour;
    private int lightsOnMinute;
    private int lightsOffMinute;
    private float targetUpperChamberHumidity;
    private float
   targetUpperChamberTemperature;
    private float
   targetLowerChamberTemperature;
    private int targetCO2PPM;
}
```

How we (temporarily) store and transmit variance in machine status:

```
public class
TransientEmbeddedSystemStateMemento {
    private long timestamp;
    private long timeLeftUnlocked;
    private float reservoirLevel;
    private float nutrientSolutionLevel;
    private float currentUpperChamberHumidity;
    private float
   currentUpperChamberTemperature;
    private float
   currentLowerChamberTemperature;
    private int currentCO2PPM;
    private boolean lit;
    private boolean powered;
    private boolean misting;
    private boolean open;
    private boolean dehumidifying;
    private boolean cooling;
    private boolean injectingCO2;
    private boolean locked;
}
```

Events and their representation:

```
public class EventRecordMemento {
    private int event;
    private long timestamp;
}

public enum EmbeddedSystemEventType {
   MIST_ON,
   MIST_OFF,
   MIN_WATER_LEVEL_REACHED,
   MAX_WATER_LEVEL_REACHED,
   MIN_NUTRIENTS_LEVEL_REACHED,
   MAX_NUTRIENT_LEVEL_REACHED,
   MISTING_WATER_PUMP_ON,
   MISTING_WATER_PUMP_OFF,
   NUTRIENTS_PUMP_ON,
   NUTRIENTS_PUMP_OFF,
   LIGHTS_ON, LIGHTS_OFF,
   POWER_ON, POWER_OFF,
   DOORS_LOCKED,
   DOORS_UNLOCKED,
   DOORS_OPEN,
   DOORS_CLOSE,
   DEHUMIDIFIER_ON,
   DEHUMIDIFIER_OFF,
   COOLING_ON,
   COOLING_OFF,
   CO2_VALVE_OPEN,
   CO2_VALVE_CLOSED
}
```

How we transmit state changes:

```
public class EmbeddedSystemConfigChangeMemento {
    private PersistentEmbeddedSystemStateMemento
    persistentState = new
    PersistentEmbeddedSystemStateMemento();
    private boolean changingMistingInterval = false;
    private boolean changingMistingDuration = false;
    private boolean changingStatusPushInterval = false;
    private boolean changingNutrientsPPM = false;
    private boolean changingNutrientSolutionRatio = false;
    private boolean changingLightsOnHour = false;
    private boolean changingLightsOffHour = false;
    private boolean changingLightsOnMinute = false;
    private boolean changingLightsOffMinute = false;
    private boolean changingTargetUpperChamberHumidity =
    false;
    private boolean changingTargetUpperChamberTemperature =
    false;
    private boolean changingTargetLowerChamberTemperature =
    false;
    private boolean changingTargetCO2PPM = false;


    public void setNoChanges() {
        setAll(false);
    }

    public void changeAll() {
        setAll(true);
    }
```

```
protected void setAll(boolean arg) {
    changingMistingInterval
            = changingMistingDuration
            = changingStatusPushInterval
            = changingNutrientsPPM
            = changingNutrientSolutionRatio
            = changingLightsOnHour
            = changingLightsOffHour
            = changingLightsOnMinute
            = changingLightsOffMinute
            = changingTargetUpperChamberHumidity
            = changingTargetUpperChamberTemperature
            = changingTargetLowerChamberTemperature
            = changingTargetCO2PPM = arg;
}

public boolean hasChanges() {
    return changingMistingInterval
            || changingMistingDuration
            || changingStatusPushInterval
            || changingNutrientsPPM
            || changingNutrientSolutionRatio
            || changingLightsOnHour
            || changingLightsOffHour
            || changingLightsOnMinute
            || changingLightsOffMinute
            || changingTargetUpperChamberHumidity
            || changingTargetUpperChamberTemperature
            || changingTargetLowerChamberTemperature
            || changingTargetCO2PPM;
}
```

How we validate this thing:

```
public class EmbeddedStateChangeValidator {
    /**
 *
 * @author noob
 * The integer arguments are to be able to use an existing
lights-on hour to test against.
 * Intended usage is for the case in which the backend is
told that the user wants to change either only the minute
or the hour setting.
 * That means it can then pull up the existing value from
already-known information and calculate,
 *  */
    public static EmbeddedSystemConfigChangeMemento
validate(EmbeddedSystemConfigChangeMemento arg, int
currentLightsOnHour, int currentLightsOnMin, int
currentLightsOffHour, int currentLightsOffMin) {
        EmbeddedSystemConfigChangeMemento req = arg;
        boolean settingLightsOnHour = false;
        boolean settingLightsOffHour = false;
        boolean settingLightsOnMinute = false;
        boolean settingLightsOffMinute = false;
        final int mistingInterval =
req.getPersistentState().getMistingInterval();
        final int mistingDuration =
req.getPersistentState().getMistingDuration();
        final int lightsOnHour =
req.getPersistentState().getLightsOnHour();
        final int lightsOnMinute =
req.getPersistentState().getLightsOnMinute();
        final int lightsOffHour =
req.getPersistentState().getLightsOffHour();
        final int lightsOffMinute =
req.getPersistentState().getLightsOffMinute();
```

```
        // Validating time
        if (req.hasChanges()) {
            if (req.isChangingLightsOnHour()) {
                settingLightsOnHour = true;
            }

            if (req.isChangingLightsOnMinute()) {
                settingLightsOnMinute = true;
            }
            if (req.isChangingLightsOffHour()) {
                settingLightsOffHour = true;
            }
            if (req.isChangingLightsOffMinute()) {
                settingLightsOffMinute = true;
            }
            boolean validOnTime = false;
            if (settingLightsOnHour &&
settingLightsOnMinute) {
                validOnTime =
TimeOfDayValidator.validate(lightsOnHour, lightsOnMinute);
            } else if (settingLightsOnHour) {
                validOnTime =
TimeOfDayValidator.validate(lightsOnHour,
currentLightsOnMin);
            } else if (settingLightsOnMinute) {
                validOnTime =
TimeOfDayValidator.validate(currentLightsOnHour,
lightsOnMinute);
            }
            if (!validOnTime) {
                req.setChangingLightsOnHour(false);
                req.setChangingLightsOnMinute(false);
            }
            boolean validOffTime = false;
            if (settingLightsOffHour &&
settingLightsOffMinute) {
                validOffTime =
TimeOfDayValidator.validate(lightsOffHour,
lightsOffMinute);
            } else if (settingLightsOffHour) {
```

```
                validOffTime =
TimeOfDayValidator.validate(lightsOffHour,
currentLightsOffMin);
            } else if (settingLightsOffMinute) {
                validOffTime =
TimeOfDayValidator.validate(currentLightsOffHour,
lightsOffMinute);
            }
            if (!validOffTime) {
                req.setChangingLightsOffHour(false);
                req.setChangingLightsOffMinute(false);
            }
            // Validating misting interval
            if (req.isChangingMistingInterval() &&
(mistingInterval > CommonValues.maxMistingInterval ||
mistingInterval < CommonValues.minMistingInterval)) {
                req.setChangingMistingInterval(false);
            }
            // Validating misting duration
            if (req.isChangingMistingDuration() &&
(mistingDuration > CommonValues.maxMistingDuration ||
mistingDuration < CommonValues.minMistingDuration)) {
                req.setChangingMistingDuration(false);
            }
            // Validating solution ratio of nutrients vs
water
            final double solutionRatio =
req.getPersistentState().getNutrientSolutionRatio();
            if (req.isChangingNutrientSolutionRatio() &&
(solutionRatio > CommonValues.maxNutrientSolutionRatio ||
solutionRatio < CommonValues.minNutrientSolutionRatio)) {

req.setChangingNutrientSolutionRatio(false);
            }
```

```
            // Validating humidity
            final float humidity =
req.getPersistentState().getTargetUpperChamberHumidity();
            if (req.isChangingTargetUpperChamberHumidity()
&& (humidity > CommonValues.maxHumidity || humidity <
CommonValues.minHumidity)) {

req.setChangingTargetUpperChamberHumidity(false);
            }
            // Validating temperature
            final float temperature =
req.getPersistentState().getTargetUpperChamberTemperature()
;

            if
(req.isChangingTargetUpperChamberTemperature() &&
(temperature > CommonValues.maxTargetTemperature ||
temperature < CommonValues.minTargetTemperature)) {

req.setChangingTargetUpperChamberTemperature(false);
            }
            final int ppm =
req.getPersistentState().getTargetCO2PPM();
            // Validating target CO2 levels
            if (req.isChangingTargetCO2PPM()) {
                if (ppm < CommonValues.minCO2PPM || ppm >
CommonValues.maxCO2PPM) {
                    req.setChangingTargetCO2PPM(false);
                }
            }
        }
        return req;
    }
}
```

(Sorry.)

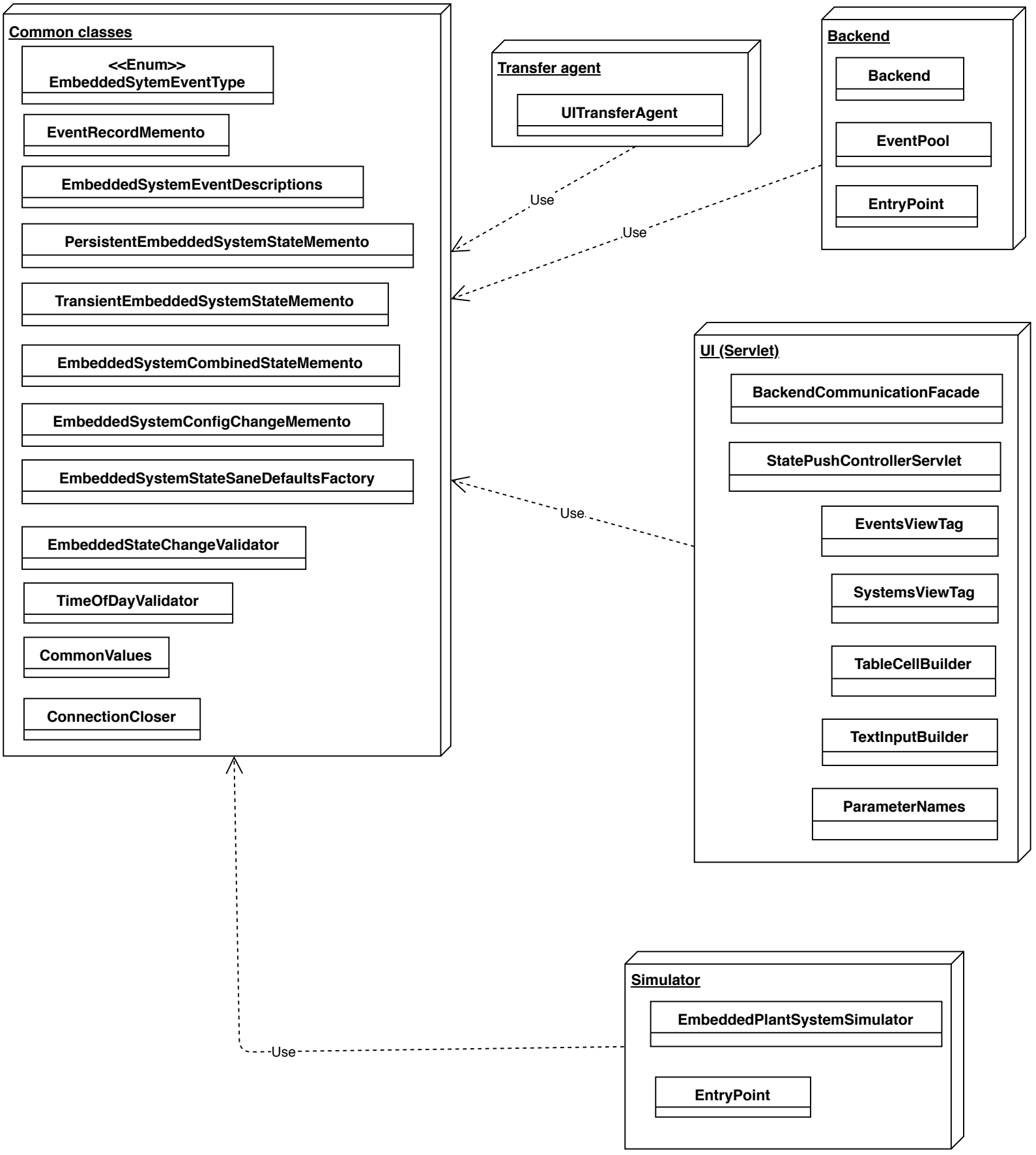
Minor point of interest:

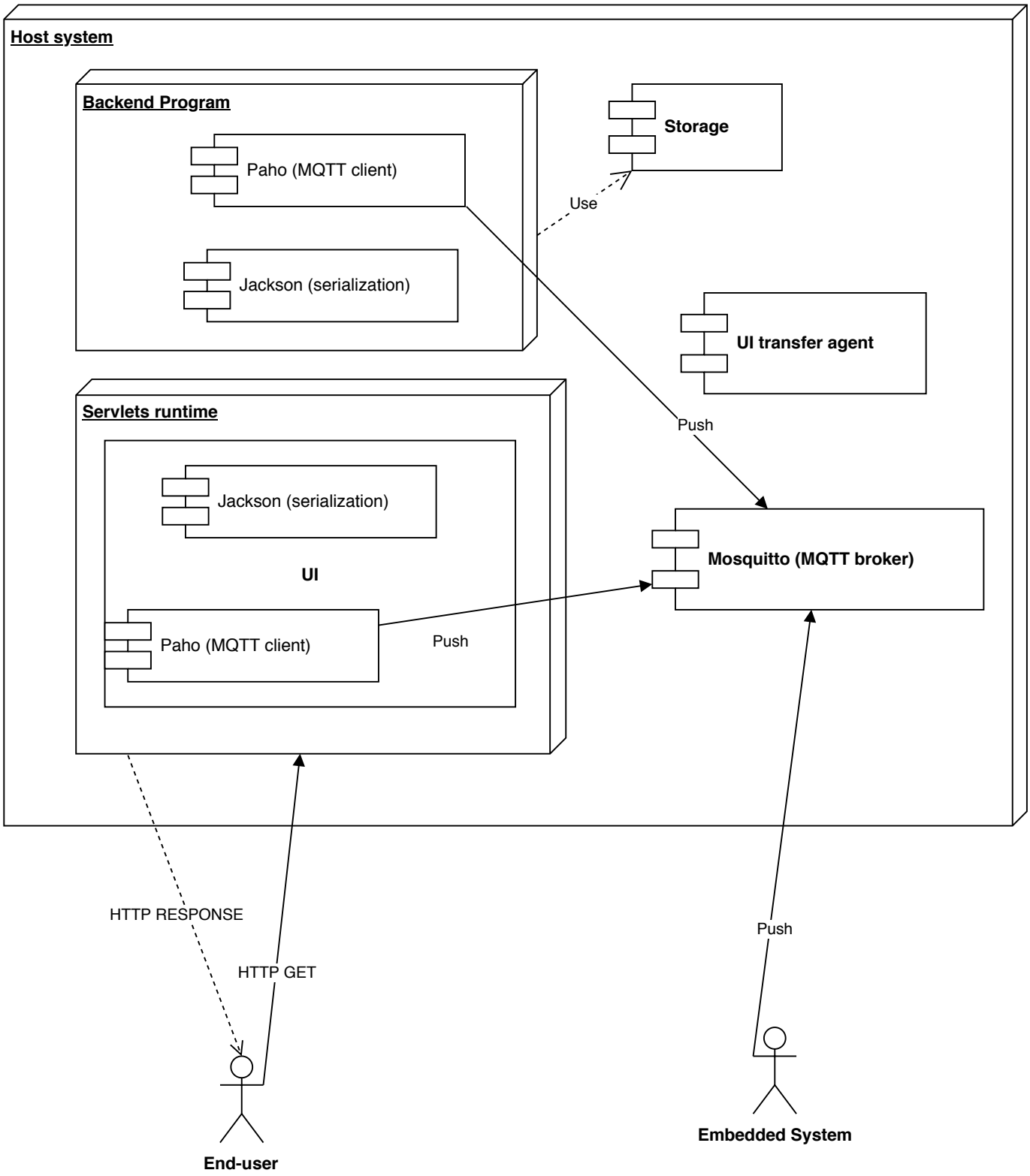
- We also implicitly use an the object pooling pattern when storing events and system state: We replace state when changing it, using the same memory location.
- Also, the EventPool preallocates a deque and pops the element off the tail prior to inserting at the head.
- Does that count? Probably.
- (I know that didn't *absolutely* need to be discussed, but it was worth talking about.)

Tools used:

- Java 8 was used (OpenJDK)
- NetBeans was grudgingly appreciated.
- Speed tests used the Selenium project, a Python toolkit for web browser testing. (Tip: Setup a VM or dedicate a machine to work with this tool because otherwise using your desktop becomes very difficult.)
- Jackson JSON library, version 3.
- If you ever use that library, ignore all the old tutorials. The new interface is so much simpler; time was definitely wasted fearing the wrath of what turned out to not exist anymore.
- Paho MQTT client library, Java implementation. Protocol version 3.1 kept in order to keep our potential replacement choices as open as possible and.
- Mosquitto MQTT broker, which is a very popular implementation.
- Git and Github were used constantly to ensure we didn't lose any valuable code that we may have stomped on.
- Servlets and custom JSP tags were used to create the web backend.
- Browser speed tests were run on everyone's favourite browser… Firefox!
- They gave us 1/3 second backend processing time, maximum.
- And before we forget, the "Solarized Dark" theme used on our web UI:

  http://thomasf.github.io/solarized-css/solarized-dark.css


Common classes
<<Enum>>
EmbeddedSytemEventType
EventRecordMemento
EmbeddedSystemEventDescriptions
PersistentEmbeddedSystemStateMemento
TransientEmbeddedSystemStateMemento
EmbeddedSystemCombinedStateMemento
EmbeddedSystemConfigChangeMemento
EmbeddedSystemStateSaneDefaultsFactory
EmbeddedStateChangeValidator
TimeOfDayValidator
CommonValues
ConnectionCloser
Transfer agent
UITransferAgent
Backend
Backend
EventPool
EntryPoint
Use
Use
UI (Servlet)
BackendCommunicationFacade
StatePushControllerServlet
EventsViewTag
SystemsViewTag
TableCellBuilder
TextInputBuilder
ParameterNames
Use
Simulator
EmbeddedPlantSystemSimulator
EntryPoint
Use


Host system
Backend Program
Paho (MQTT client)
Jackson (serialization)
Storage
Use
UI transfer agent
Servlets runtime
Push
Jackson (serialization)
UI
Mosquitto (MQTT broker)
Paho (MQTT client)
Push
HTTP RESPONSE
HTTP GET
Push
End-user
Embedded System