Observer Design Pattern
Event-Driven Design

EECS3311 A: Software Design
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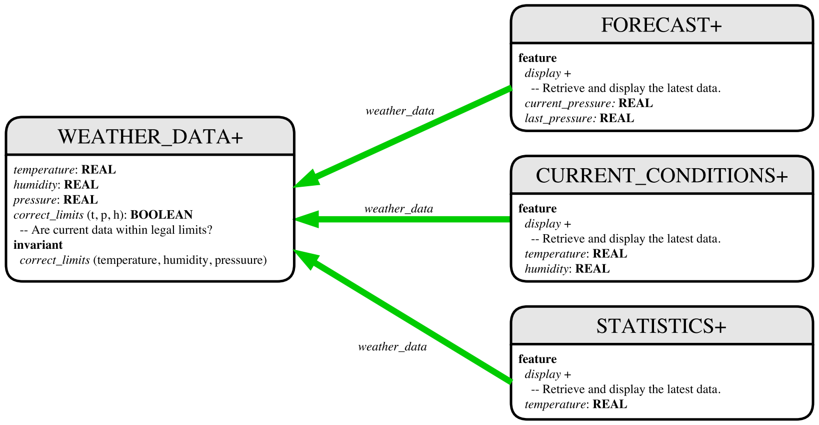
Motivating Problem

- A *weather station* maintains *weather data* such as *temperature*, *humidity*, and *pressure*.
- Various kinds of applications on these *weather data* should regularly update their *displays*:
  - *Forecast*: if expecting for rainy weather due to reduced *pressure*.
  - *Condition*: *temperature* in celsius and *humidity* in percentages.
  - *Statistics*: minimum/maximum/average measures of *temperature*.

First Design: Weather Station



Whenever the `display` feature is called, **retrieve** the current values of `temperature`, `humidity`, and/or `pressure` via the `weather_data` reference.

Implementing the First Design (1)

```
class WEATHER_DATA create make
feature -- Data
  temperature: REAL
  humidity: REAL
  pressure: REAL
feature -- Queries
  correct_limits(t,p,h: REAL): BOOLEAN
    ensure
      Result implies -36 <=t and t <= 60
      Result implies 50 <= p and p <= 110
      Result implies 0.8 <= h and h <= 100
feature -- Commands
  make (t, p, h: REAL)
    require
      correct_limits(temperature, pressure, humidity)
    ensure
      temperature = t and pressure = p and humidity = h
invariant
  correct_limits(temperature, pressure, humidity)
end
```

Implementing the First Design (2.1)

```
class FORECAST create make
feature -- Attributes
  current_pressure: REAL
  last_pressure: REAL
  weather_data: WEATHER_DATA
feature -- Commands
  make(wd: WEATHER_DATA)
    ensure weather_data = wd
  update
    do last_pressure := current_pressure
       current_pressure := weather_data.pressure
    end
  display
    do update
       if current_pressure > last_pressure then
        print("Improving weather on the way!%N")
       elseif current_pressure = last_pressure then
        print("More of the same%N")
       else print("Watch out for cooler, rainy weather%N") end
    end
end
```

Implementing the First Design (2.2)

```
class CURRENT_CONDITIONS create make
feature -- Attributes
  temperature: REAL
  humidity: REAL
  weather_data: WEATHER_DATA
feature -- Commands
  make(wd: WEATHER_DATA)
    ensure weather_data = wd
  update
    do temperature := weather_data.temperature
       humidity := weather_data.humidity
    end
  display
    do update
       io.put_string("Current Conditions: ")
       io.put_real (temperature) ; io.put_string (" degrees C and ")
       io.put_real (humidity) ; io.put_string (" percent humidity%N")
    end
end
```

Implementing the First Design (2.3)

```
class STATISTICS create make
feature -- Attributes
  weather_data: WEATHER_DATA
  current_temp: REAL
  max, min, sum_so_far: REAL
  num_readings: INTEGER
feature -- Commands
  make(wd: WEATHER_DATA)
    ensure weather_data = wd
  update
    do current_temp := weather_data.temperature
       -- Update min, max if necessary.
    end
  display
    do update
       print("Avg/Max/Min temperature = ")
       print(sum_so_far / num_readings + "/" + max + "/" min + "%N")
    end
end
```

Implementing the First Design (3)

```
 1  class WEATHER_STATION create make
 2  feature -- Attributes
 3    cc: CURRENT_CONDITIONS ; fd: FORECAST ; sd: STATISTICS
 4    wd: WEATHER_DATA
 5  feature -- Commands
 6    make
 7      do create wd.make (9, 75, 25)
 8         create cc.make (wd) ; create fd.make (wd) ; create sd.make(wd)
 9
10         wd.set_measurements (15, 60, 30.4)
11         cc.display ; fd.display ; sd.display
12         cc.display ; fd.display ; sd.display
13
14         wd.set_measurements (11, 90, 20)
15         cc.display ; fd.display ; sd.display
16    end
17  end
```

L14: Updates occur on `cc`, `fd`, `sd` even with the same data.

First Design: Good Design?

- Each application (CURRENT_CONDITION, FORECAST, STATISTICS) *cannot know* when the weather data change.

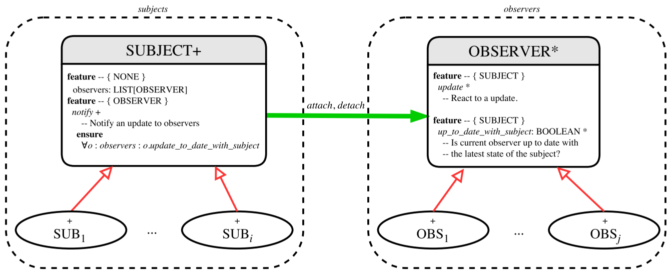
  ⇒ All applications have to periodically initiate updates in order to keep the display results up to date.

  ∵ Each inquiry of current weather data values is *a remote call*.

  ∴ Waste of computing resources (e.g., network bandwidth) when there are actually no changes on the weather data.
- To avoid such overhead, it is better to let:
  - Each application is ***subscribed/attached/registered*** to the weather data.
  - The weather data ***publish/notify*** new changes.

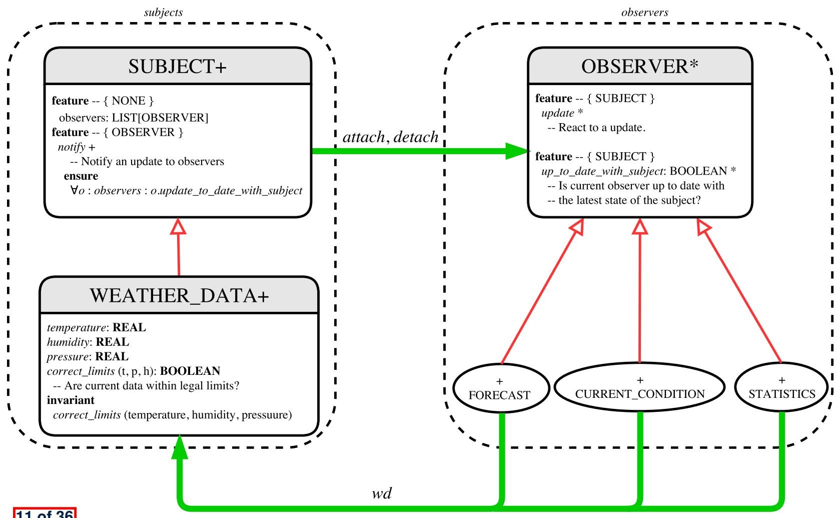
    ⇒ Updates on the application side occur only *when necessary*.

Observer Pattern: Architecture


subjects
SUBJECT+
feature -- { NONE }
observers: LIST[OBSERVER]
feature -- { OBSERVER }
notify +
-- Notify an update to observers
ensure
∀o : observers : o.update_to_date_with_subject
attach, detach
observers
OBSERVER*
feature -- { SUBJECT }
update *
-- React to a update.
feature -- { SUBJECT }
up_to_date_with_subject: BOOLEAN *
-- Is current observer up to date with
-- the latest state of the subject?
SUB1
...
SUBi
OBS1
...
OBSj

- Observer (publish-subscribe) pattern: *one-to-many* relation.
  - Observers (*subscribers*) are attached to a subject (*publisher*).
  - The subject notify its attached observers about changes.
- Some interchangeable vocabulary:
  - subscribe ≈ attach ≈ register
  - unsubscribe ≈ detach ≈ unregister
  - publish ≈ notify
  - handle ≈ update

Observer Pattern: Weather Station


subjects
SUBJECT+
feature -- { NONE }
observers: LIST[OBSERVER]
feature -- { OBSERVER }
notify +
-- Notify an update to observers
ensure
∀o : observers : o.update_to_date_with_subject
WEATHER_DATA+
temperature: REAL
humidity: REAL
pressure: REAL
correct_limits (t, p, h): BOOLEAN
-- Are current data within legal limits?
invariant
correct_limits (temperature, humidity, pressure)
attach, detach
observers
OBSERVER*
feature -- { SUBJECT }
update *
-- React to a update.
feature -- { SUBJECT }
up_to_date_with_subject: BOOLEAN *
-- Is current observer up to date with
-- the latest state of the subject?
FORECAST
CURRENT_CONDITION
STATISTICS
wd

Implementing the Observer Pattern (1.1)

```
class SUBJECT create make
feature -- Attributes
  observers : LIST[OBSERVER]
feature -- Commands
  make
   do create {LINKED_LIST[OBSERVER]} observers.make
   ensure no_observers:  observers.count = 0 end
feature -- Invoked by an OBSERVER
  attach (o: OBSERVER) -- Add 'o' to the observers
    require not_yet_attached: not observers.has (o)
    ensure is_attached: observers.has (o) end
  detach (o: OBSERVER) -- Add 'o' to the observers
    require currently_attached: observers.has (o)
    ensure is_attached: not observers.has (o) end
feature -- invoked by a SUBJECT
  notify -- Notify each attached observer about the update.
    do across observers as cursor loop cursor.item.update end
    ensure all_views_updated:
      across observers as o all o.item.up_to_date_with_subject end
    end
end
```

Implementing the Observer Pattern (1.2)

```
class WEATHER_DATA
inherit SUBJECT  rename make as make_subject end
create make
feature -- data available to observers
  temperature: REAL
  humidity: REAL
  pressure: REAL
  correct_limits(t,p,h: REAL): BOOLEAN
feature -- Initialization
  make (t, p, h: REAL)
    do
      make_subject -- initialize empty observers
      set_measurements (t, p, h)
    end
feature -- Called by weather station
  set_measurements(t, p, h: REAL)
    require correct_limits(t,p,h)
invariant
  correct_limits(temperature, pressure, humidity)
end
```

Implementing the Observer Pattern (2.1)

```
deferred class
  OBSERVER
feature -- To be effected by a descendant
  up_to_date_with_subject: BOOLEAN
      -- Is this observer up to date with its subject?
    deferred
    end

  update
      -- Update the observer's view of 's'
    deferred
    ensure
      up_to_date_with_subject: up_to_date_with_subject
    end
end
```

Each effective descendant class of OBSERVER should:

- Define what weather data are required to be up-to-date.
- Define how to update the required weather data.

Implementing the Observer Pattern (2.2)

```
class FORECAST
inherit OBSERVER
feature -- Commands
  make(a_weather_data: WEATHER_DATA)
    do weather_data := a_weather_data
       weather_data.attach (Current)
    ensure weather_data = a_weather_data
           weather_data.observers.has (Current)
    end
feature -- Queries
  up_to_date_with_subject: BOOLEAN
    ensure then
      Result = current_pressure = weather_data.pressure
  update
    do -- Same as 1st design; Called only on demand
    end
  display
    do -- No need to update; Display contents same as in 1st design
    end
end
```

Implementing the Observer Pattern (2.3)

```
class CURRENT_CONDITIONS
inherit OBSERVER
feature -- Commands
  make(a_weather_data: WEATHER_DATA)
    do weather_data := a_weather_data
       weather_data.attach (Current)
    ensure weather_data = a_weather_data
           weather_data.observers.has (Current)
    end
feature -- Queries
  up_to_date_with_subject: BOOLEAN
    ensure then Result = temperature = weather_data.temperature and
                         humidity = weather_data.humidity
  update
    do -- Same as 1st design; Called only on demand
    end
  display
    do -- No need to update; Display contents same as in 1st design
    end
end
```

Implementing the Observer Pattern (2.4)

```
class STATISTICS
inherit OBSERVER
feature -- Commands
  make(a_weather_data: WEATHER_DATA)
    do weather_data := a_weather_data
       weather_data.attach (Current)
    ensure weather_data = a_weather_data
           weather_data.observers.has (Current)
    end
feature -- Queries
  up_to_date_with_subject: BOOLEAN
    ensure then
      Result = current_temperature = weather_data.temperature
  update
    do -- Same as 1st design; Called only on demand
    end
  display
    do -- No need to update; Display contents same as in 1st design
    end
end
```

Implementing the Observer Pattern (3)

```
1  class WEATHER_STATION create make
2  feature -- Attributes
3    cc: CURRENT_CONDITIONS ; fd: FORECAST ; sd: STATISTICS
4    wd: WEATHER_DATA
5  feature -- Commands
6    make
7      do create wd.make (9, 75, 25)
8         create cc.make (wd) ; create fd.make (wd) ; create sd.make(wd)
9
10        wd.set_measurements (15, 60, 30.4)
11        wd.notify
12        cc.display ; fd.display ; sd.display
13        cc.display ; fd.display ; sd.display
14
15        wd.set_measurements (11, 90, 20)
16        wd.notify
17        cc.display ; fd.display ; sd.display
18     end
19 end
```

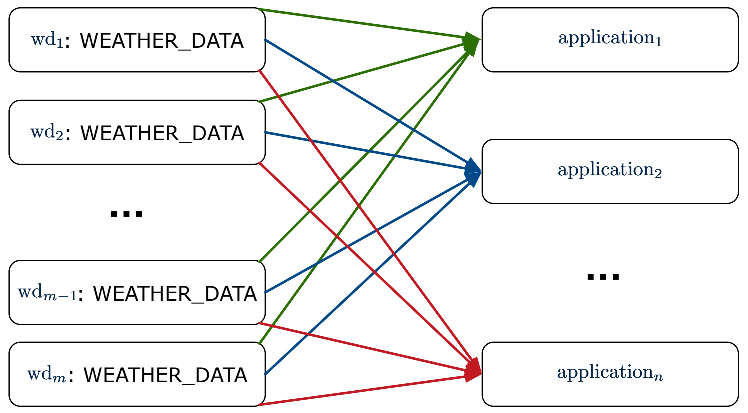
L13: `cc`, `fd`, `sd` make use of "cached" data values.

Observer Pattern: Limitation? (1)

- The *observer design pattern* is a reasonable solution to building a *one-to-many* relationship: one subject (publisher) and multiple observers (subscribers).
- But what if a *many-to-many* relationship is required for the application under development?
  - *Multiple* *weather data* are maintained by weather stations.
  - Each application observes *all* these *weather data*.
  - But, each application still stores the *latest* measure only. e.g., the statistics app stores one copy of `temperature`
  - Whenever some weather station updates the `temperature` of its associated *weather data*, all **relevant** subscribed applications (i.e., current conditions, statistics) should update their temperatures.
- How can the observer pattern solve this general problem?
  - Each *weather data* maintains a list of subscribed *applications*.
  - Each *application* is subscribed to *multiple* *weather data*.

Observer Pattern: Limitation? (2)

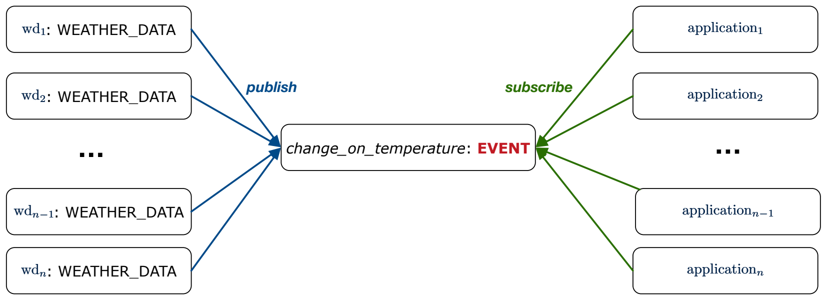
What happens at runtime when building a *many-to-many* relationship using the *observer pattern*?


wd_1: WEATHER_DATA
wd_2: WEATHER_DATA
...
wd_{m-1}: WEATHER_DATA
wd_m: WEATHER_DATA
application_1
application_2
...
application_n

Graph complexity, with m subjects and n observers? [$O(m \cdot n)$]

Event-Driven Design (1)

Here is what happens at runtime when building a *many-to-many* relationship using the *event-driven design*.



Graph complexity, with m subjects and n observers?	$[O(m+n)]$
Additional cost by adding a new subject?	$[O(1)]$
Additional cost by adding a new observer?	$[O(1)]$
Additional cost by adding a new event type?	$[O(m+n)]$

Event-Driven Design (2)

In an *event-driven design*:

- Each variable being observed (e.g., `temperature`, `humidity`, `pressure`) is called a *monitored variable*.

  e.g., A nuclear power plant (i.e., the ***subject***) has its `temperature` and `pressure` being *monitored* by a shutdown system (i.e., an ***observer***): as soon as values of these *monitored variables* exceed the normal threshold, the SDS will be notified and react by shutting down the plant.
- Each *monitored variable* is declared as an *event*:
  - An ***observer*** is ***attached***/***subscribed*** to the relevant events.
    - `CURRENT_CONDITION` attached to events for `temperature`, `humidity`.
    - `FORECAST` only subscribed to the event for `pressure`.
    - `STATISTICS` only subscribed to the event for `temperature`.
  - A ***subject*** ***notifies***/***publishes*** changes to the relevant events.

Event-Driven Design: Example

Darlington Nuclear Generating System (by Ontario Power Generation)

Image Source: `https://www.opg.com`

Event-Driven Design: Implementation

- Requirements for implementing an *event-driven design* are:
  1. When an ***observer*** object is *subscribed to* an ***event***, it attaches:
     1.1 The **reference**/**pointer** to an update operation
     Such reference/pointer is used for $\boxed{\text{delayed}}$ executions.
     1.2 Itself (i.e., the **context object** for invoking the update operation)
  2. For the ***subject*** object to *publish* an update to the ***event***, it:
     2.1 Iterates over its (previously) attached operation **references**/**pointers**
     2.2 Invokes these operations, which update the corresponding observers
- Both requirements can be satisfied by Eiffel and Java.
- We will compare how an *event-driven design* for the weather station problems is implemented in Eiffel and Java.

  ⇒ It is more convenient to implement such design in Eiffel.

Event-Driven Design in Java (1)

```
1  public class Event {
2    Hashtable<Object, MethodHandle> listenersActions;
3    Event() { listenersActions = new Hashtable<>(); }
4    void subscribe(Object listener, MethodHandle action) {
5      listenersActions.put( listener , action );
6    }
7    void publish(Object arg) {
8      for (Object listener : listenersActions.keySet()) {
9        MethodHandle action = listenersActions.get(listener);
10       try {
11         action .invokeWithArguments( listener , arg);
12       } catch (Throwable e) { }
13     }
14   }
15 }
```

- **L5**: Both the delayed `action` reference and its context object (or call target) `listener` are stored into the table.
- **L11**: An invocation is made from retrieved `listener` and `action`.

Event-Driven Design in Java (2)

```
1  public class WeatherData {
2    private double temperature;
3    private double pressure;
4    private double humidity;
5    public WeatherData(double t, double p, double h) {
6      setMeasurements(t, h, p);
7    }
8    public static Event changeOnTemperature = new Event();
9    public static Event changeOnHumidity = new Event();
10   public static Event changeOnPressure = new Event();
11   public void setMeasurements(double t, double h, double p) {
12     temperature = t;
13     humidity = h;
14     pressure = p;
15     changeOnTemperature .publish(temperature);
16     changeOnHumidity .publish(humidity);
17     changeOnPressure .publish(pressure);
18   }
19 }
```

Event-Driven Design in Java (3)

```
1  public class CurrentConditions {
2    private double temperature; private double humidity;
3    public void updateTemperature(double t) { temperature = t; }
4    public void updateHumidity(double h) { humidity = h; }
5    public CurrentConditions() {
6      MethodHandles.Lookup lookup = MethodHandles.lookup();
7      try {
8        MethodHandle ut = lookup.findVirtual(
9          this.getClass(), "updateTemperature",
10         MethodType.methodType(void.class, double.class));
11       WeatherData.changeOnTemperature.subscribe(this, ut);
12       MethodHandle uh = lookup.findVirtual(
13         this.getClass(), "updateHumidity",
14         MethodType.methodType(void.class, double.class));
15       WeatherData.changeOnHumidity.subscribe(this, uh);
16     } catch (Exception e) { e.printStackTrace(); }
17   }
18   public void display() {
19     System.out.println("Temperature: " + temperature);
20     System.out.println("Humidity: " + humidity); } }
```

Event-Driven Design in Java (4)

```
1  public class WeatherStation {
2    public static void main(String[] args) {
3      WeatherData wd = new WeatherData(9, 75, 25);
4      CurrentConditions cc = new CurrentConditions();
5      System.out.println("=======");
6      wd.setMeasurements(15, 60, 30.4);
7      cc.display();
8      System.out.println("=======");
9      wd.setMeasurements(11, 90, 20);
10     cc.display();
11 } }
```

L4 invokes

`WeatherData.changeOnTemperature.subscribe(`
`cc, ``updateTemperature handle'')`

L6 invokes

`WeatherData.changeOnTemperature.publish(15)`

which in turn invokes

`` ``updateTemperature handle''.invokeWithArguments(cc, 15) ``

Event-Driven Design in Eiffel (1)

```
1  class EVENT [ARGUMENTS -> TUPLE ]
2  create make
3  feature -- Initialization
4   actions: LINKED_LIST[PROCEDURE[ARGUMENTS]]
5   make do create actions.make end
6  feature
7   subscribe (an_action: PROCEDURE[ARGUMENTS])
8     require action_not_already_subscribed: not actions.has(an_action)
9     do actions.extend (an_action)
10    ensure action_subscribed: action.has(an_action) end
11  publish (args: ARGUMENTS)
12    do from actions.start until actions.after
13       loop actions.item.call (args) ; actions.forth end
14    end
15 end
```

- **L1** constrains the generic parameter ARGUMENTS: any class that instantiates ARGUMENTS must be a ***descendant*** of TUPLE.
- **L4**: The type ***PROCEDURE*** encapsulates both the context object and the reference/pointer to some update operation.

Event-Driven Design in Eiffel (2)

```
1  class WEATHER_DATA
2  create make
3  feature -- Measurements
4   temperature: REAL ; humidity: REAL ; pressure: REAL
5   correct_limits(t,p,h: REAL): BOOLEAN do ... end
6   make (t, p, h: REAL) do ... end
7  feature -- Event for data changes
8    change_on_temperature : EVENT[TUPLE[REAL]]once create Result end
9    change_on_humidity : EVENT[TUPLE[REAL]]once create Result end
10   change_on_pressure : EVENT[TUPLE[REAL]]once create Result end
11 feature -- Command
12  set_measurements(t, p, h: REAL)
13    require correct_limits(t,p,h)
14    do temperature := t ; pressure := p ; humidity := h
15       change_on_temperature .publish ([t])
16       change_on_humidity .publish ([p])
17       change_on_pressure .publish ([h])
18    end
19 invariant correct_limits(temperature, pressure, humidity) end
```

Event-Driven Design in Eiffel (3)

```
1  class CURRENT_CONDITIONS
2  create make
3  feature -- Initialization
4   make(wd: WEATHER_DATA)
5    do
6     wd.change_on_temperature.subscribe (agent update_temperature)
7     wd.change_on_humidity.subscribe (agent update_humidity)
8    end
9  feature
10  temperature: REAL
11  humidity: REAL
12  update_temperature (t: REAL) do temperature := t end
13  update_humidity (h: REAL) do humidity := h end
14  display do ... end
15 end
```

- **agent** cmd retrieves the pointer to cmd and its context object.
- **L6** ≈ ... (**agent** ***Current***.update_temperature)
- Contrast **L6** with **L8–11** in Java class CurrentConditions.

Event-Driven Design in Eiffel (4)

```
1  class WEATHER_STATION create make
2  feature
3   cc: CURRENT_CONDITIONS
4   make
5    do create wd.make (9, 75, 25)
6       create cc.make (wd)
7       wd.set_measurements (15, 60, 30.4)
8       cc.display
9       wd.set_measurements (11, 90, 20)
10      cc.display
11   end
12 end
```

L6 invokes

```
wd.change_on_temperature.subscribe(
    agent cc.update_temperature)
```

L7 invokes

```
wd.change_on_temperature.publish([15])
```

which in turn invokes `cc.update_temperature(15)`

Event-Driven Design: Eiffel vs. Java

- *Storing observers/listeners of an event*
  - Java, in the `Event` class:

```
Hashtable<Object, MethodHandle> listenersActions;
```

  - Eiffel, in the `EVENT` class:

```
actions: LINKED_LIST[PROCEDURE[ARGUMENTS]]
```

- *Creating and passing function pointers*
  - Java, in the `CurrentConditions` class constructor:

```
  MethodHandle ut = lookup.findVirtual(
    this.getClass(), "updateTemperature",
    MethodType.methodType(void.class, double.class));
  WeatherData.changeOnTemperature.subscribe(this, ut);
```

  - Eiffel, in the `CURRENT_CONDITIONS` class construction:

```
  wd.change_on_temperature.subscribe (agent update_temperature)
```

⇒ Eiffel's type system has been better thought-out for *design* .

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