Observer Design Pattern
Event-Driven Design

EECS3311 A & E: Software Design
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Learning Objectives

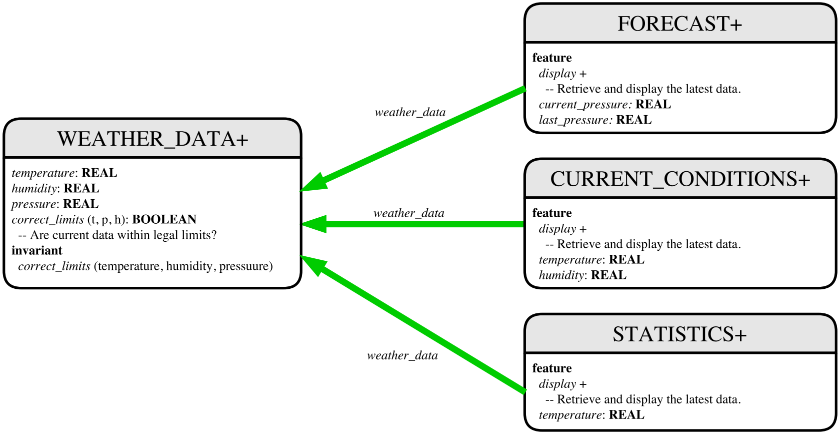
1. Motivating Problem: ***Distributed*** Clients and Servers
2. First Design Attempt: Remote Procedure Calls
3. Second Design Attempt: ***Observer Design Pattern***
4. Third Design Attempt: ***Event-Driven Design*** (Java vs. Eiffel)
5. Use of `agent`

   [≈ C function pointers ≈ C# delegates ≈ Java lambda]

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(t, p, h)
   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.

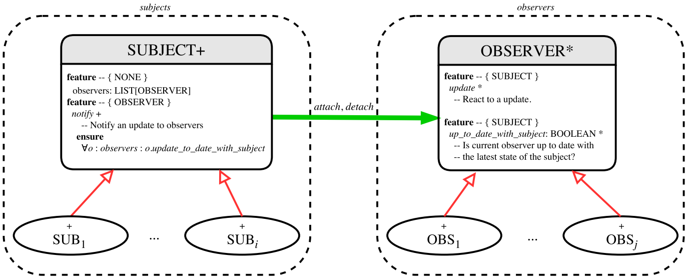
  ⇒ All applications have to periodically initiate updates in order to keep the `display` results up to date.

  ∵ 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.

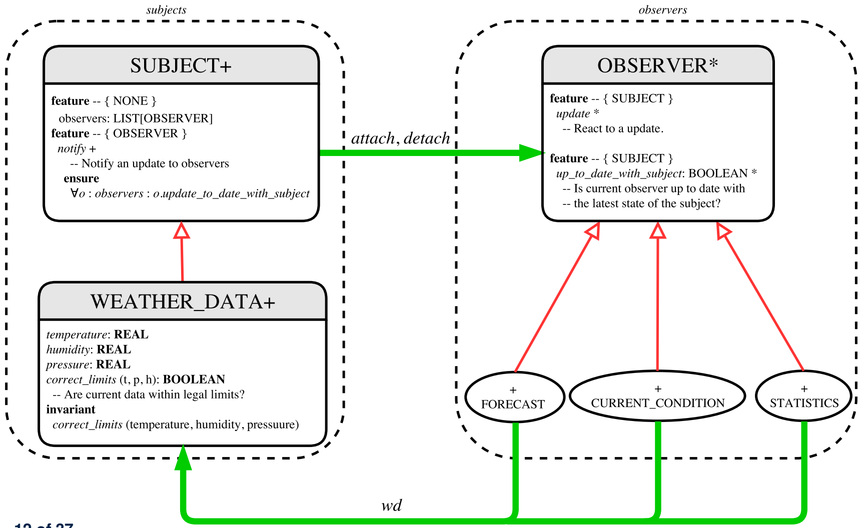
    ⇒ Updates on the application side occur only *when necessary* .

Observer Pattern: Architecture


subjects
observers
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
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, pressuure)
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
```

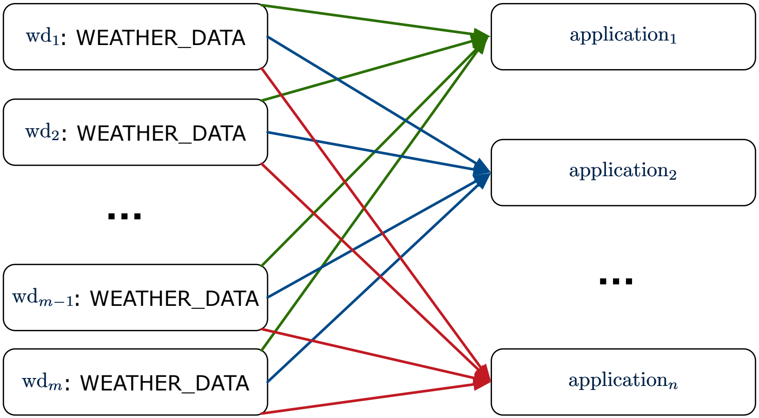
L13: `cc`, `fd`, `sd` make use of "cached" data values.

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)

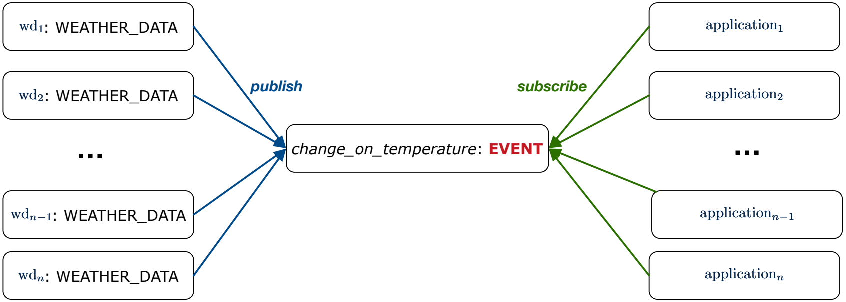
What happens at runtime when building a *many-to-many* relationship using the *observer pattern*?


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*.



wd_1: WEATHER_DATA
wd_2: WEATHER_DATA
...
wd_{n-1}: WEATHER_DATA
wd_n: WEATHER_DATA
publish
change_on_temperature: EVENT
subscribe
$\mathrm{application}_1$
$\mathrm{application}_2$
...
$\mathrm{application}_{n-1}$
$\mathrm{application}_n$

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: 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 through all its observers (or listeners)
     - 2.2 Uses the operation reference/pointer (attached earlier) to update the corresponding observer.
- 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's much more convenient to do such design in Eiffel.

Event-Driven Design in Java (1)

```java
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)

```
public class WeatherData {
  private double temperature;
  private double pressure;
  private double humidity;
  public WeatherData(double t, double p, double h) {
    setMeasurements(t, h, p);
  }
  public static Event changeOnTemperature = new Event();
  public static Event changeOnHumidity = new Event();
  public static Event changeOnPressure = new Event();
  public void setMeasurements(double t, double h, double p) {
    temperature = t;
    humidity = h;
    pressure = p;
    changeOnTemperature.publish(temperature);
    changeOnHumidity.publish(humidity);
    changeOnPressure.publish(pressure);
  }
}
```

Event-Driven Design in Java (3)

```java
public class CurrentConditions {
  private double temperature; private double humidity;
  public void updateTemperature(double t) { temperature = t; }
  public void updateHumidity(double h) { humidity = h; }
  public CurrentConditions() {
    MethodHandles.Lookup lookup = MethodHandles.lookup();
    try {
      MethodHandle ut = lookup.findVirtual(
        this.getClass(), "updateTemperature",
        MethodType.methodType(void.class, double.class));
      WeatherData.changeOnTemperature.subscribe(this, ut);
      MethodHandle uh = lookup.findVirtual(
        this.getClass(), "updateHumidity",
        MethodType.methodType(void.class, double.class));
      WeatherData.changeOnHumidity.subscribe(this, uh);
    } catch (Exception e) { e.printStackTrace(); }
  }
  public void display() {
    System.out.println("Temperature: " + temperature);
    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 [ARGUMENT -> TUPLE ]
2  create make
3  feature -- Initialization
4    actions: LINKED_LIST[PROCEDURE [ARGUMENT]]
5    make do create actions.make end
6  feature
7    subscribe (an_action: PROCEDURE [ARGUMENT])
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: ARGUMENT)
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 `ARGUMENT`: any class that instantiates `ARGUMENT` 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)

```
class WEATHER_DATA
create make
feature -- Measurements
  temperature: REAL ; humidity: REAL ; pressure: REAL
  correct_limits(t,p,h: REAL): BOOLEAN do ... end
  make (t, p, h: REAL) do ... end
feature -- Event for data changes
  change_on_temperature : EVENT[TUPLE[REAL]]once create Result end
  change_on_humidity : EVENT[TUPLE[REAL]]once create Result end
  change_on_pressure : EVENT[TUPLE[REAL]]once create Result end
feature -- Command
  set_measurements(t, p, h: REAL)
    require correct_limits(t,p,h)
    do temperature := t ; pressure := p ; humidity := h
       change_on_temperature .publish ([t])
       change_on_humidity .publish ([p])
       change_on_pressure .publish ([h])
    end
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 $\boxed{\texttt{cc.update\_temperature(15)}}$

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[ARGUMENT]]
```

- *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*.

Beyond this lecture. . .

Play with the source code of with the various designs (with an IDE debugger):

◦ `non_observer.zip`	[1st Design Attempt]
◦ `observer.zip`	[Observer Design Pattern]
◦ `JavaObserverEvent.zip`	[Event-Driven Design in Java]
◦ `observer_event.zip`	[Event-Driven Design in Eiffel]

Index (1)

Index (2)

Index (3)