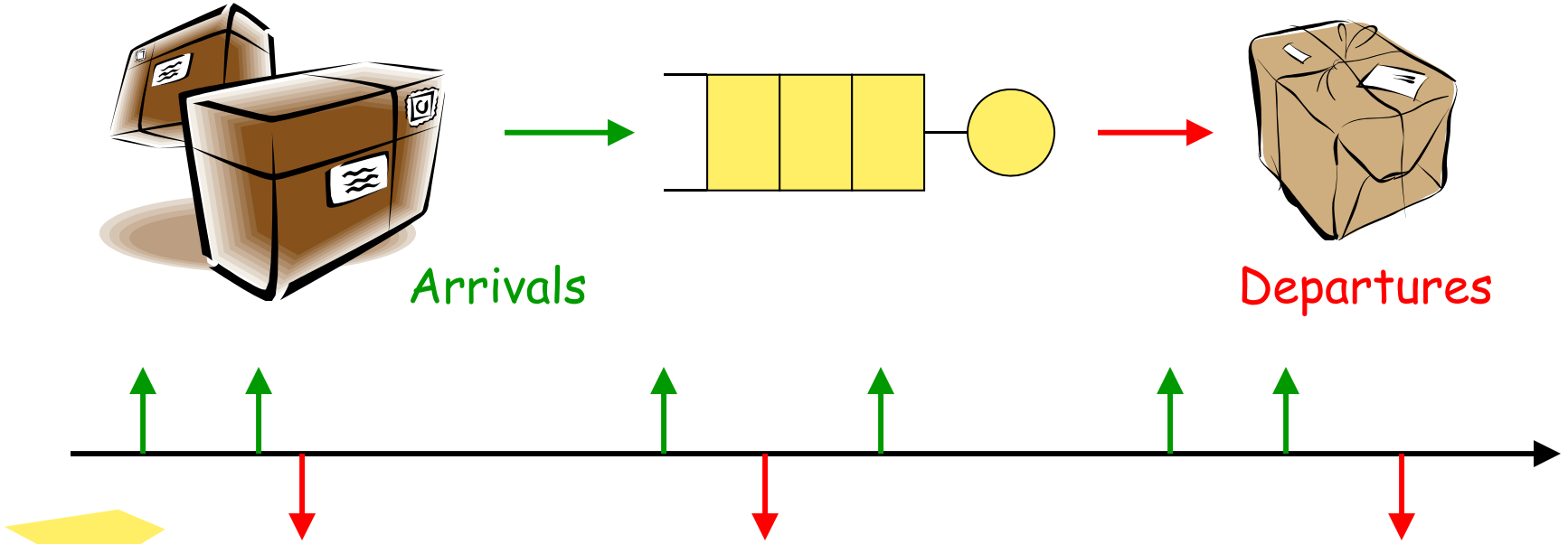
Event Driven Simulation in NS2

Outline

- Recap: Discrete Event v.s. Time Driven
- Events and Handlers
- The Scheduler
- The Simulator
- Summary

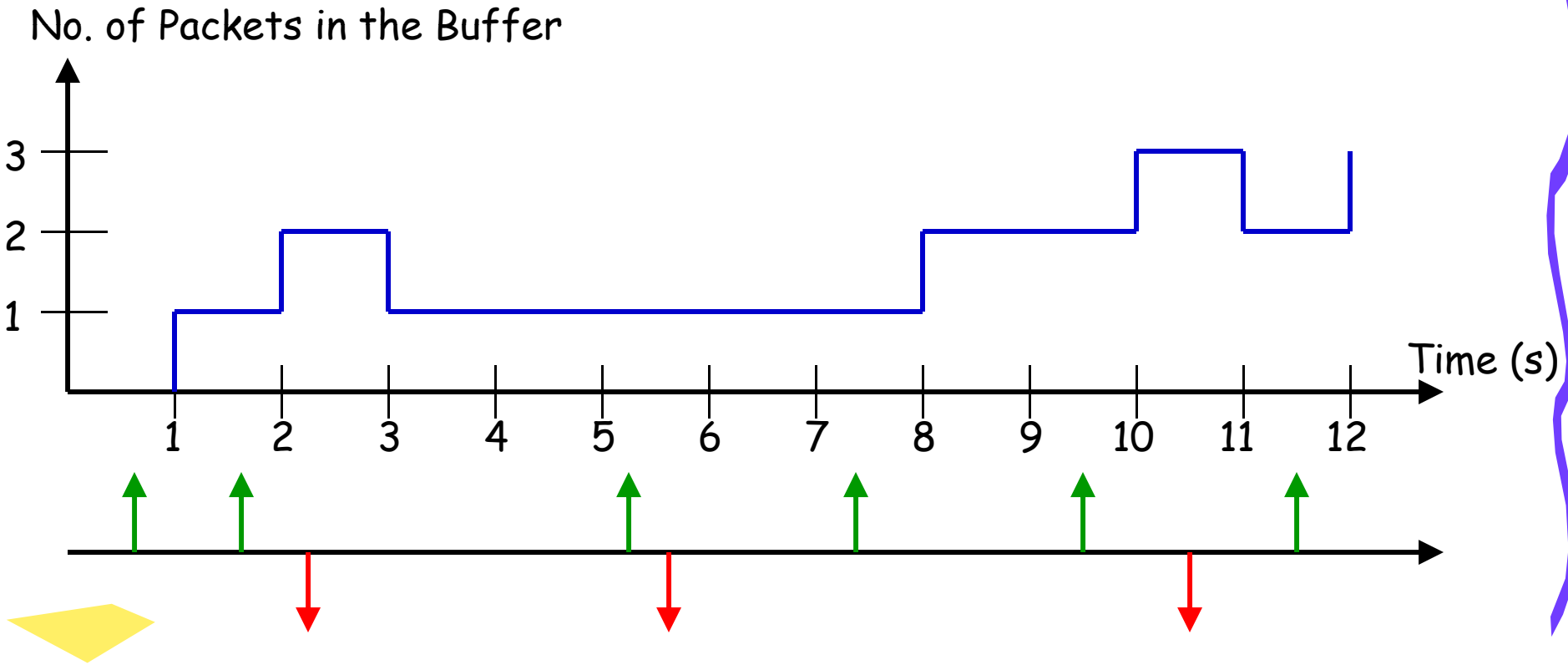
Event-Driven v.s. Time-Driven

- Q: Time Driven = ( )
- Q: Event Driven = ( )
- Time Driven or Discrete Time Simulation
- Example: Packet arrivals and departures



Time-Driven Simulation

- Observe the buffer for every FIXED period (e.g., 1 second)



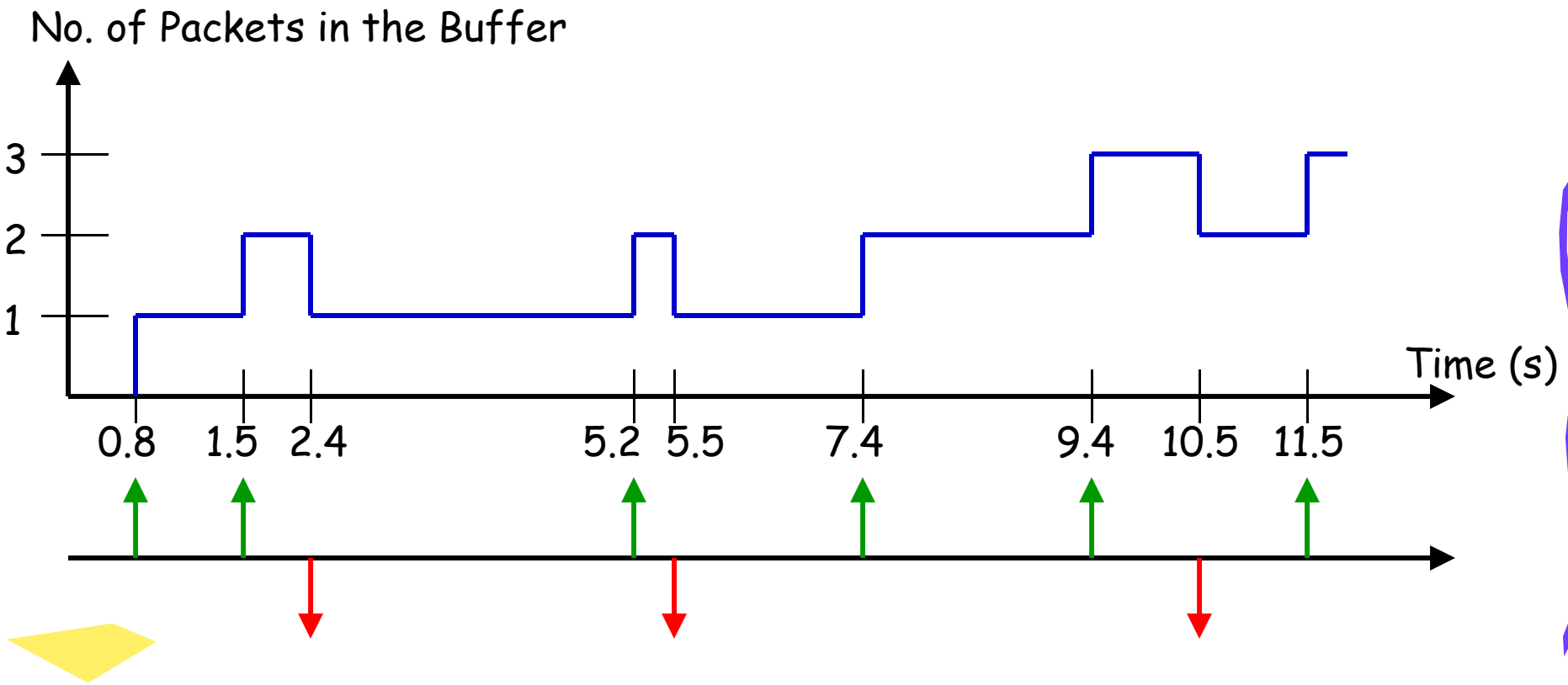
Time-Driven Simulation

- Simulation event for every time slot (fixed interval)
- Example Psudo Codes:

```
For t = 1 to sim_time {
  if (arrival)
     buffer = buffer + 1;
  if (departure)
     buffer = buffer -1;
  print(buffer);
}
```

Event-Driven Simulation

- Go from one event to another
- Same Example



Event-Driven Simulation

- Use a Scheduler
- Maintain a set of events
- Example

```
CreateEvent();
Run ();
```

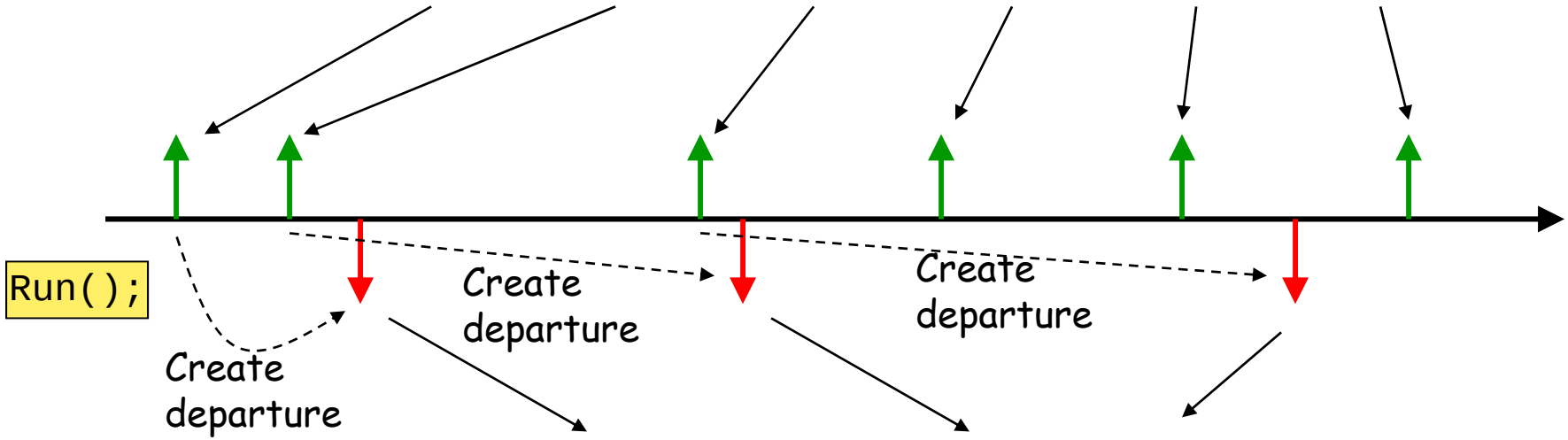
Psudo Codes

```
CreateEvent(){
Pkt1.arr(0.8)
Pkt2.arr(1.5)
}
```

Event-Driven Simulation

`CreateEvent();`

Event ID	1	2	3	4	5	6
Type	Arrival	Arrival	Arrival	Arrival	Arrival	Arrival
Time	0.8	1.5	5.2	7.4	9.4	11.5



Event ID	7	8	9
Type	Departure	Departure	Departure
Time	2.4	5.5	10.5

NS2 Simulation Concept

- Event-Driven Simulation
- Recap: Simulation Main Steps
  - Design
  - Simulation
    - Network Configuration Phase ➔ `CreateEvent()`
    - Simulation Phase ➔ `Run()`
  - Result Compilation

Simulation

- Network Configuration Phase
  - Create topology
  - Schedule event (e.g., `CreateEvent()`)
- Simulation Phase
  - `Simulator::run()` (e.g., `Run()`)
  - Execute the scheduled events

Outline

- Recap: Discrete Event v.s. Time Driven
- Events and Handlers
- The Scheduler
- The Simulator
- Summary

Event and Handler: Outline

- Overview
- C++ Classes Event and Handler
- Two Main Types of Events
  - AtEvent
  - Packet

Concepts of Events and Handlers

- Event-driven simulation
  - Put events on the simulation timeline
  - Move forward in time
  - When finding an event, take associated actions (i.e., execute the event)
- Main components
  - Events → C++ class `Event`
  - Actions → C++ class `Handler`

Q: Give examples of events.

Event and Handler

- Examples of Events
  - Packet Arrivals/Departures
  - Start/Stop Application

```
$ns at 0.05 "$ftp start"
$ns at 0.1  "$cbr start"
$ns at 60.0 "$ftp stop"
$ns at 60.5 "$cbr stop"
$ns at 61 "finish"
```

Event and Handler: C++ Classes

- Class `Event`: Define events (e.g., packet arrival)

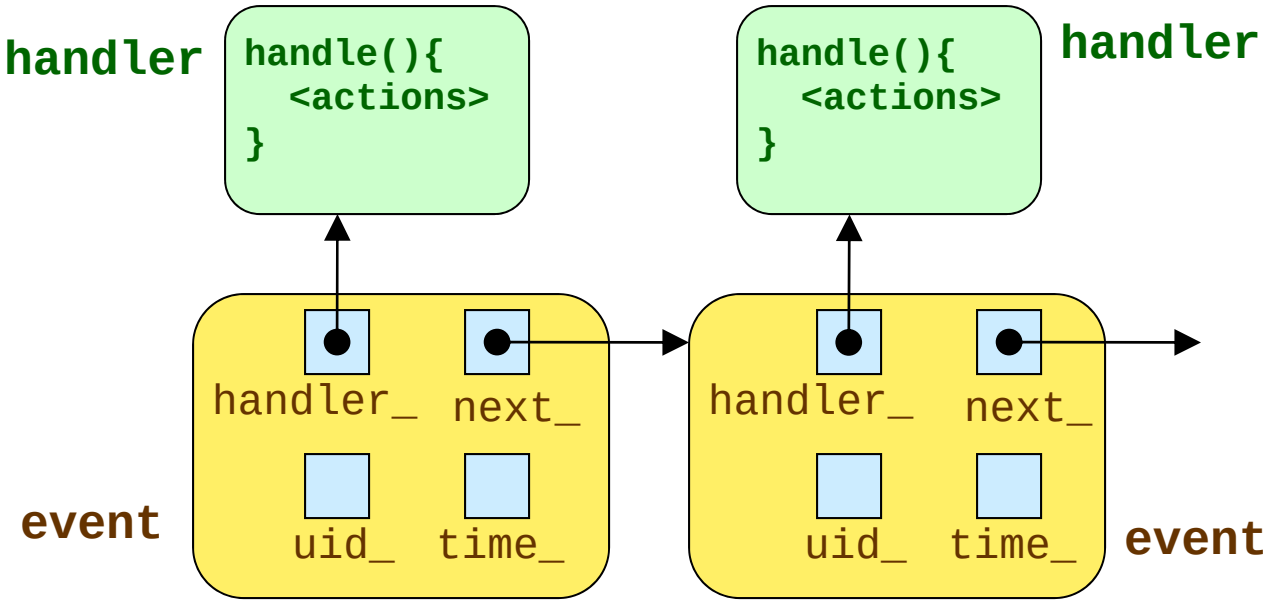
- Class `Handler`: Define (default) actions associated with an event (tell the node to receive the packet)

C++ Class Event

```
//~/ns/common/scheduler.h
class Event {
public:
    Event* next_;        /* event list */
    Event* prev_;
    Handler* handler ;  /* handler to call when event ready */
    double time_;        /* time at which event is ready */
    scheduler_uid_t uid_;   /* unique ID */
    Event() : time_(0), uid_(0) {}
};
```

Class Event

- Main variables:
  - `next_`: Next event
  - `time_`: Time
  - `uid_`: Unique ID
  - `handler_`: Handler



Textbook: T. Issariyakul and E. Hossain, *Introduction to Network Simulator NS2*, Springer 2008.

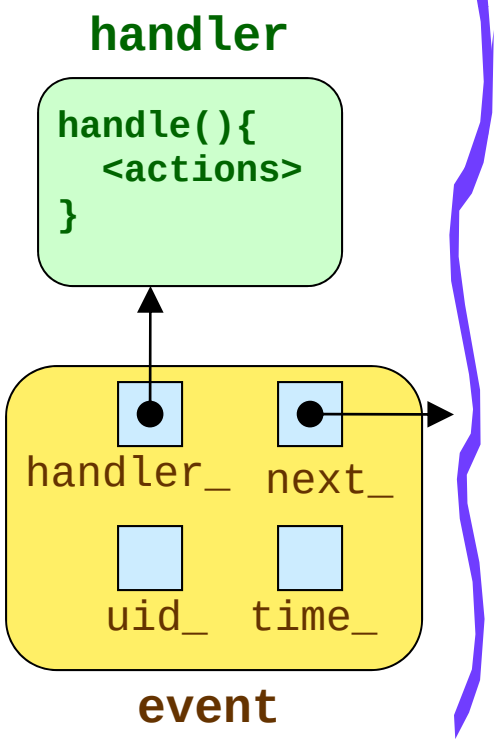
Class Handler

- Declaration

```
//~/ns/common/scheduler.h
class Handler {
public:
    virtual ~Handler () {}
    virtual void handle(Event* e) = 0;
};
```

What is this?
What is the purpose?

- Define Default Actions
  - ➔ C++ function `handle(Event*)`
- Associated with an Event



Handlers: Example

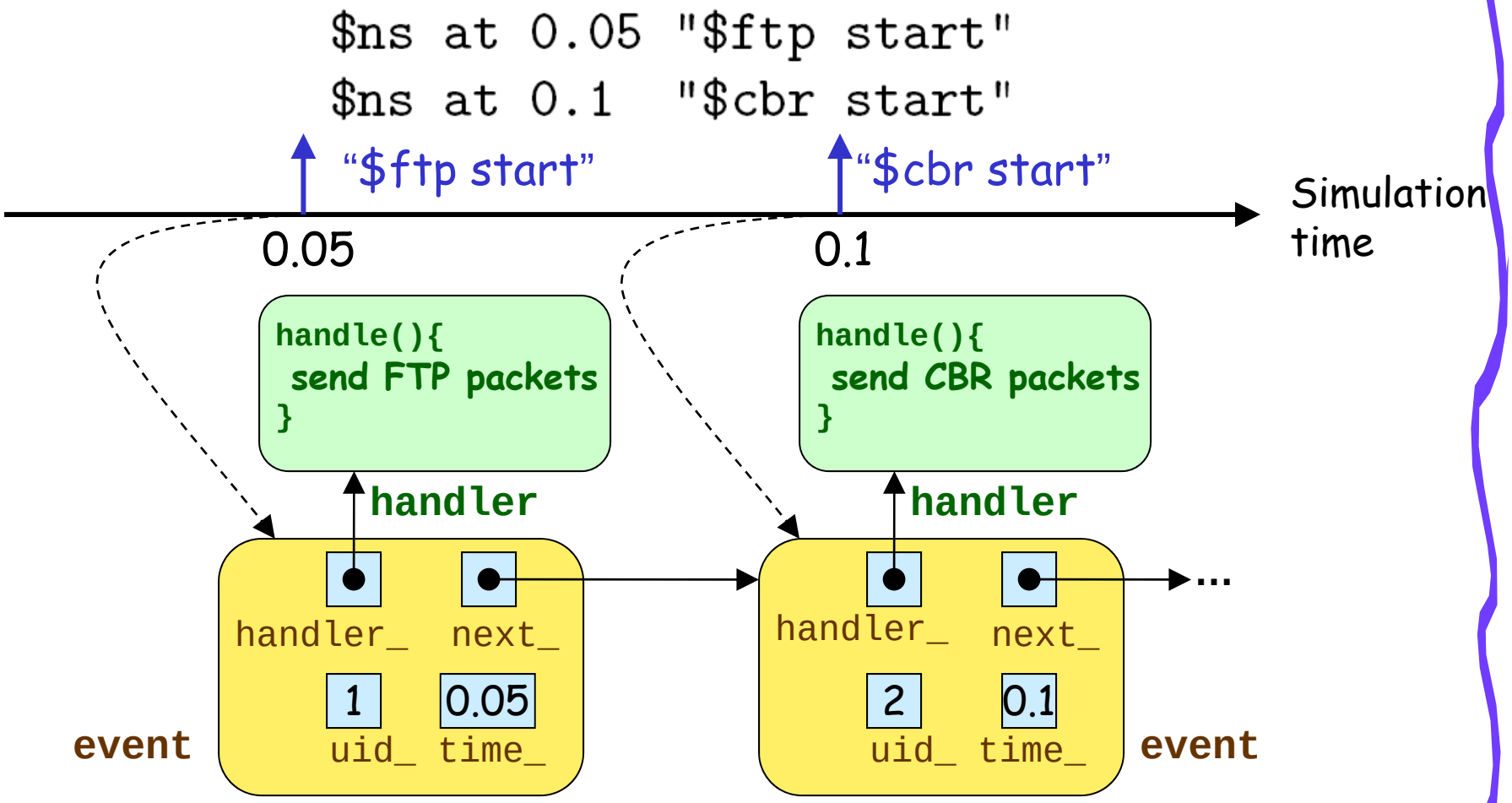
- Class `NsObject` (derived from class `Handler`)

```
//~/ns/common/object.cc
void NsObject::handle(Event* e)
{
    recv((Packet*)e);
}
```

- As we shall see, all network objects (e.g., `Connector`, `TcpAgent`) derived from class `NsObject`.

- Default action of all network objects is "to receive (using function `recv(…)`) a packet (cast from an event e)"

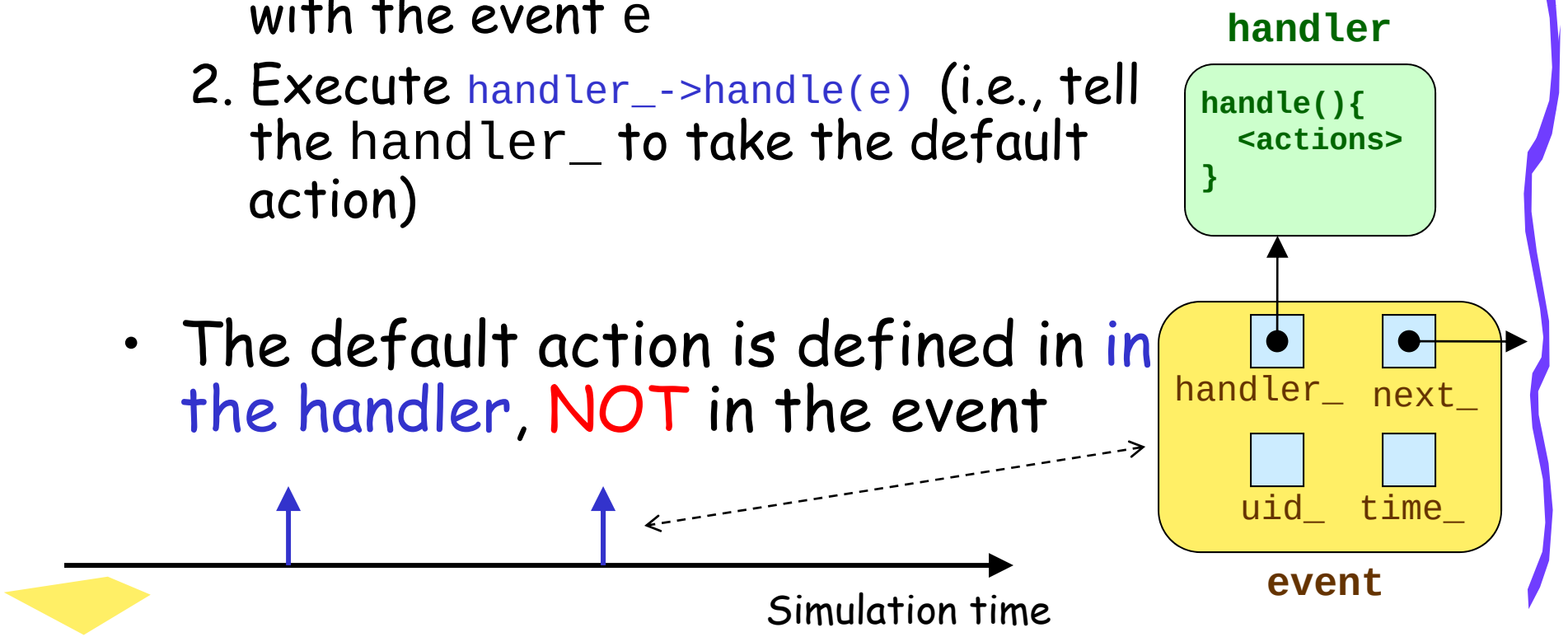
Events and Handlers: Example



Events and Handlers: Example

- When hitting an event e, a Scheduler
  1. Extract the `handler_` associated with the event e
  2. Execute `handler_->handle(e)` (i.e., tell the `handler_` to take the default action)

- The default action is defined in in the handler, NOT in the event



Question

- What is the main purpose of events ?
- What happen if NS2 does not define classes `Event`, `Handler`, and `Scheduler`?

Event and Handler: Outline

- Overview
- C++ Classes Event and Handler
- Two Main Types of Events
  - AtEvent
  - Packet (Discussed Later)

Two Types of Events

1. At Event: (Derives from Class `Event`)
   - Action: Execute an OTcl command
   - Examples:

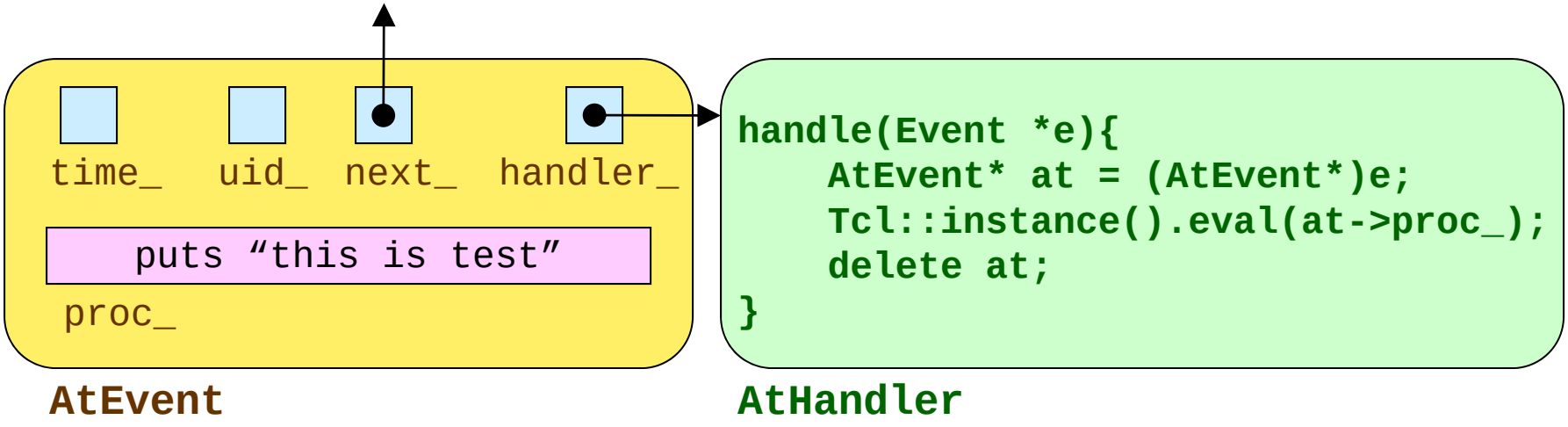
```
$ns at 0.05 "$ftp start"
$ns at 0.1  "$cbr start"
$ns at 60.0 "$ftp stop"
```

   - C++ Class `AtEvent`
   - Placed on the simulation timeline by instproc "`at`" with syntax

```
$ns at <time> <Tcl command>
```

C++ Class AtEvent

```
class AtEvent : public Event {
public:
    AtEvent() : proc_(0) {}
    char* proc_;
};
```



C++ Class AtEvent

- OTcl command: `$ns at <time> <Tcl command>`
- Implementation:

```
Scheduler::command(int argc, const char*const* argv)
{
      Tcl& tcl = Tcl::instance();
      if (argc == 4) {
         if (strcmp(argv[1], "at") == 0) {
                  double delay, t = atof(argv[2]); const char* proc = argv[3];
                  AtEvent* e = new AtEvent;int n = strlen(proc);
                  e->proc_ = new char[n + 1];
                  strcpy(e->proc_, proc);
                  delay = t - clock();
                  schedule(&at_handler, e, delay);
                  return (TCL_OK);
         }
      }
      return (TclObject::command(argc, argv));
}
```

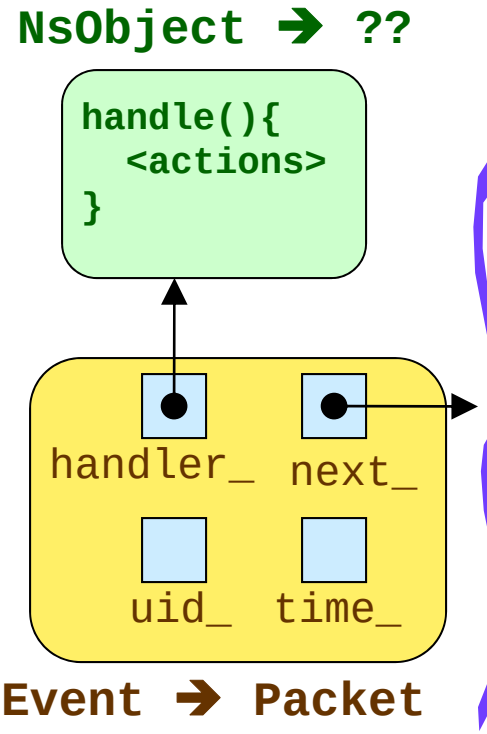
Q: argv[0] = ? ( )

Two Types of Events

2. Packet: (Derives from Class Event)
   - Action: Receive a packet

```
//~/ns/common/object.cc
void NsObject::handle(Event* e)
{
        recv((Packet*)e);
}
```

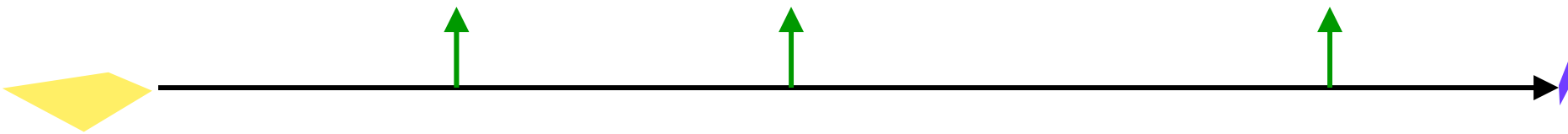
??



   - C++ Class Packet (will be discussed later)

Questions

- Q: How do we put an AtEvent on the simulation timeline? ( )
- Q: Is it possible to put a Packet on the simulation timeline? Why or why not? ( )
- How do we put events on the simulation timeline? ➔ Use THE SCHEDULER



Outline

- Recap: Discrete Event v.s. Time Driven
- Events and Handlers
- The Scheduler
- The Simulator
- Summary

The Scheduler: Outline

- Overview
- C++ Class Scheduler
- Unique ID and Its Mechanism
- Scheduling and Dispatching Mechansim
- Null Events and Dummy Events

Event Handling: Recap

1. Put events on the simulation timeline
2. Take the default action assoc. with (i.e., handle) event ➔ Handler
   - Also called "fire" or "dispatch"
   - function `handle()` of class `Handler`
3. Move to the next event ➔ Scheduler
   - Through the pointer "`next_`" of an `Event` object

How do we "PUT", "TAKE", and "MOVE"?

Recap

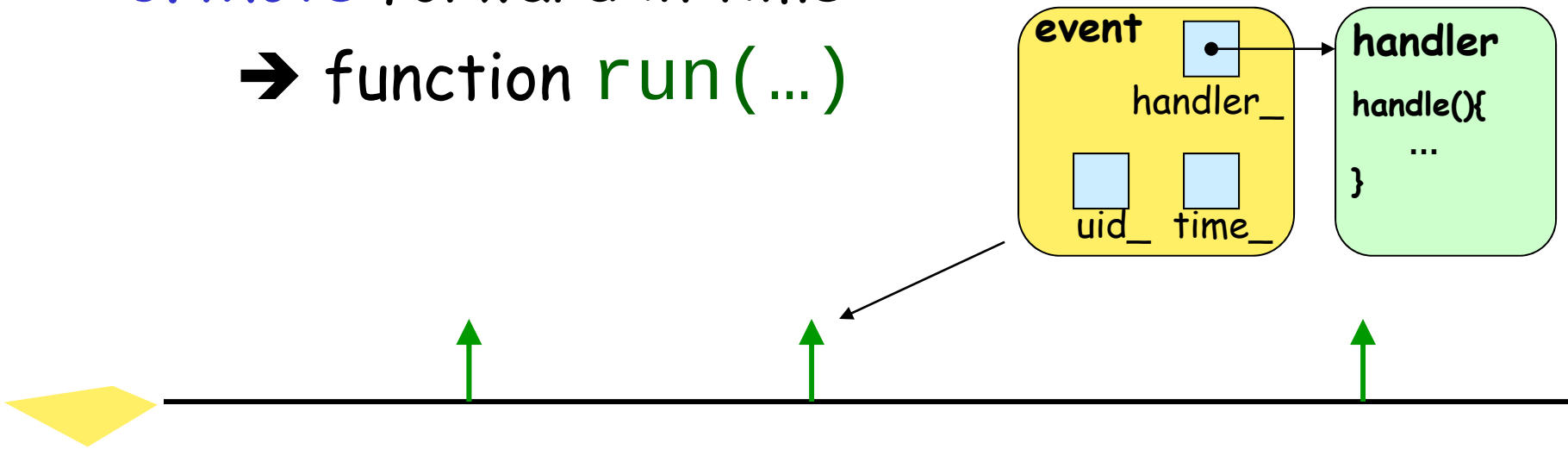
- Event e = An indication of future event
- Handler defines the default action (i.e., how to execute the event e; `handler(e)`)
- NS2 moves forwards in time and tell the relevant handler to execute default actions.
- Execute = Fire = Dispatch

- What's more?
  - How to put an event on the simulation timeline?
  - Who should execute the actions assoc. with the event?

➔THE SCHEDULER

The Scheduler

1. Put events on the simulation timeline
   - ➔ function `schedule(…)`
2. Take the default action
   - ➔ function `dispatch(…)`
3. Move forward in time
   - ➔ function `run(…)`



C++ Class Scheduler

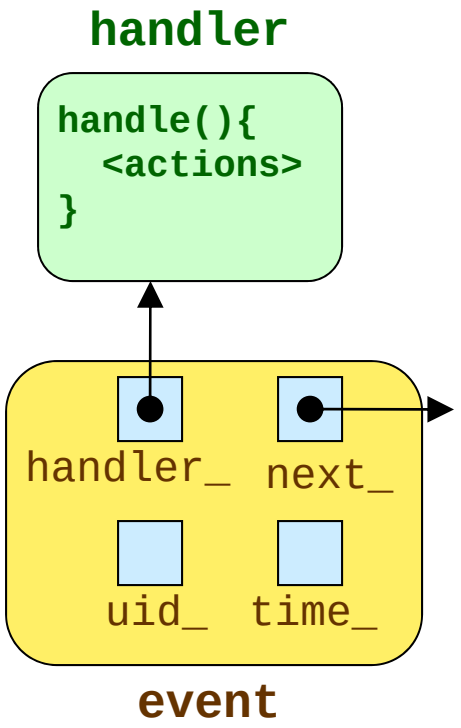
```
class Scheduler : public TclObject {
public:
    static Scheduler& instance() { return (*instance_); }
    void schedule(Handler*, Event*, double delay);
    virtual void run();
    virtual void cancel(Event*) = 0;
    virtual void insert(Event*) = 0;
    virtual Event* lookup(scheduler_uid_t uid) = 0;
    virtual Event* deque() = 0;
    virtual const Event* head() = 0;
    double clock() const { return (); }
    virtual void reset();
protected:
    void dispatch(Event*);
    void dispatch(Event*, double);
    Scheduler();
    virtual ~Scheduler();
    int command(int argc, const char*const* argv);
    double clock_;
    static Scheduler* instance_;
    static scheduler_uid_t uid_;
    int halted_;
};
```

Current virtual time

Unique ID: incremented for every new event

Task 1: Put Event on the Simulation Timeline

- Use function `schedule(h,e,delay)`
  - Associate Event "`e`" with a handler "`h`"
  - Indicate the dispatching time
  - Assign unique ID
  - Put the Event "`e`" on the simulation time with delay "`delay`"



Functions schedule(.)

```
void Scheduler::schedule(Handler* h, Event* e, double delay)
{
     < Checking for Error >
     e->uid_ = uid_++;
     e->handler_ = h;
     double t = clock_ + delay;
     e->time_ = t;
     insert(e);
}
```

New unique ID

Bind "e" and "h"

Update time

Put "e" on the time line

Function schedule(.)

- 4 Possible errors
  1. Null handler (i.e., `h = 0`)

```
if (!h) { /* error: Do not feed in NULL handler */ };
```

We will talk about this error later

  2. `uid_` of the event > 0 ➔ Something wrong

```
if (e->uid_ > 0) {
    printf("Scheduler: Event UID not valid!\n\n");
    abort();
}
```

This is a very common error message!!

Function schedule(.)

- 4 Possible errors

3. `delay < 0` ➔ Go back in time

```
if (delay < 0) { /* error: negative delay */ };
```

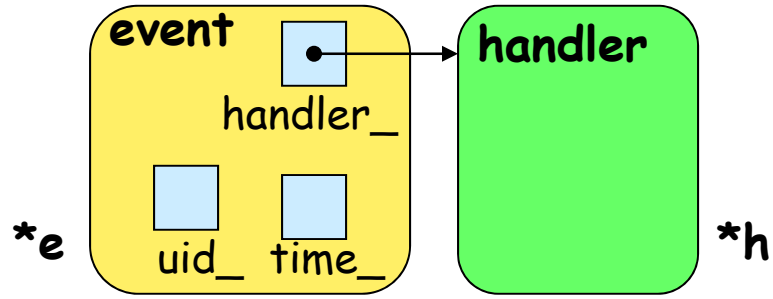
4. `uid_ < 0` ➔ Use up the `uid_`

```
if (uid_ < 0) {
 fprintf(stderr, "Scheduler: UID space exhausted!\n")
 abort();
}
```

Task 2: Take Default Actions

- NS2 "dispatches" a relevant handler to take default actions.

```
void Scheduler::dispatch(Event* p, double t)
{
    if (t < clock_) { /* error */ };
    clock_ = t;
    p->uid_ = -p->uid_;      // being dispatched
    p->handler_->handle(p); // dispatch
}
```



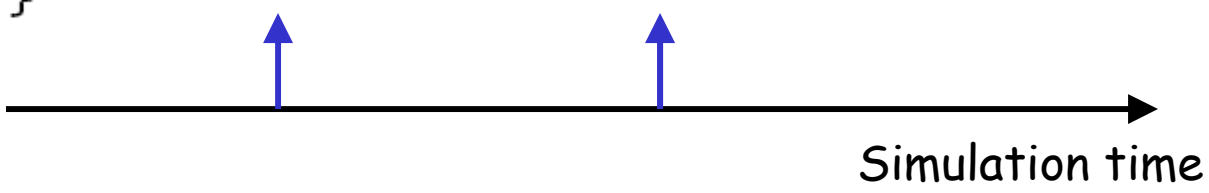
Why put negative?
➔ We will discuss about the sign of uid_ later.

Task 3: Move from One Event to the Next

- Function `run()` starts the simulation

```
//~ns/common/scheduler.cc
void scheduler::run()
{
    instance_ = this;
    Event *p;
    while (!halted_ && (p = deque())) {
        dispatch(p, p->time_);
    }
}
```

Take the "**next**" event from the queue of events



The Scheduler: Outline

- Overview
- C++ Class Scheduler
- Unique ID and Its Mechanism
- Scheduling and Dispatching Mechanism
- Null Events and Dummy Events

Two types of Unique ID (UID)

- 1. Scheduler:
  - Global UID
  - Track the number of created UID

```
class Scheduler : public TclObject {
public:
    ...
    static scheduler_uid_t uid_;
};
```

- 2. Event:
  - Individual UID
  - Event ID
  - Assigned by the Scheduler

```
class Event {
public:
...
    scheduler_uid_t uid_;
};
```

Global UID

- A member variable of class `Scheduler`
- Always Positive
- Incremented for every new event (fn `schedule(.)`)

```
void Scheduler::schedule(Handler* h, Event* e, double delay)
{
...
    if (uid_ < 0) {
        fprintf(stderr, "Scheduler: UID space exhausted!\n");
        abort();
    }
    e->uid_ = uid_++;
    ...
}
```

Individual UID

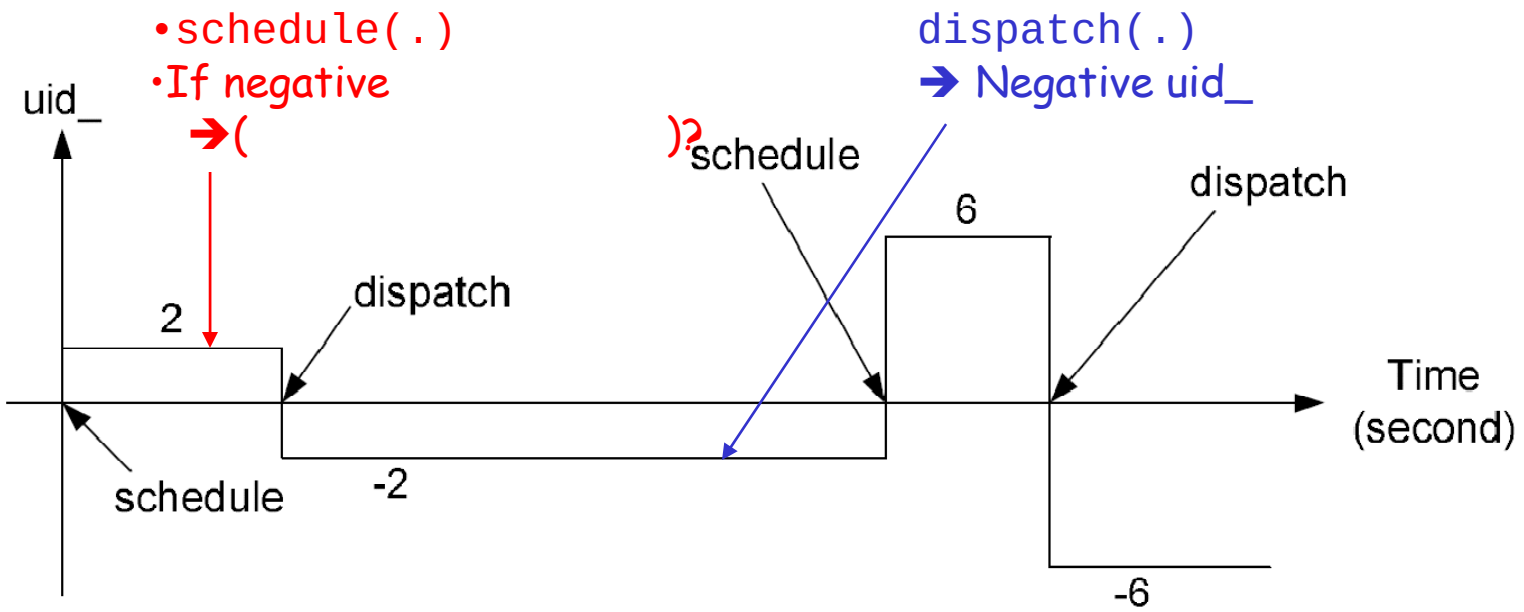
- Unique to each event
  - Set by the Scheduler
  - Assigned by the Scheduler within fn `schedule(.)`
  - Negated by the invocation of fn `dispatch(.)`

```
void Scheduler::schedule(Handler* h, Event* e, double delay)
{
    if (e->uid_ > 0) {
        printf("Scheduler: Event UID not valid!\n\n");
        abort();
    }
    e->uid_ = uid_++;
}
```

```
void Scheduler::dispatch(Event* p, double t)
{
    ...
    p->uid_ = -p->uid_;    // being dispatched
    ...
}
```

Individual UID

- Unique to each event
  - Positive: assigned by fn `schedule(.)`
  - Negative: dispatched fn `dispatch(.)`
  - Dynamics: `uid_` is switching between +/- values



Individual UID

- Positive UID
  - The event is on the simulation time line.
  - It is waiting to be executed.
  - Rescheduling the (undispatched) event here would result in an error

uid_ of the event > 0 ➔ Something wrong:

```
if (e->uid_ > 0) {
    printf("Scheduler: Event UID not valid!\n\n");
    abort();
}
```

Individual UID

- Positive UID
  - The event is on the simulation time line.
  - It is waiting to be executed.
  - Rescheduling the (undispatched) event here would result in an error
- Negative UID
  - The event has been executed.
  - It is ready to be rescheduled.

The Scheduler: Outline

- Overview
- C++ Class Scheduler
- Unique ID and Its Mechanism
- Scheduling and Dispatching Mechanism
- Null Events and Dummy Events

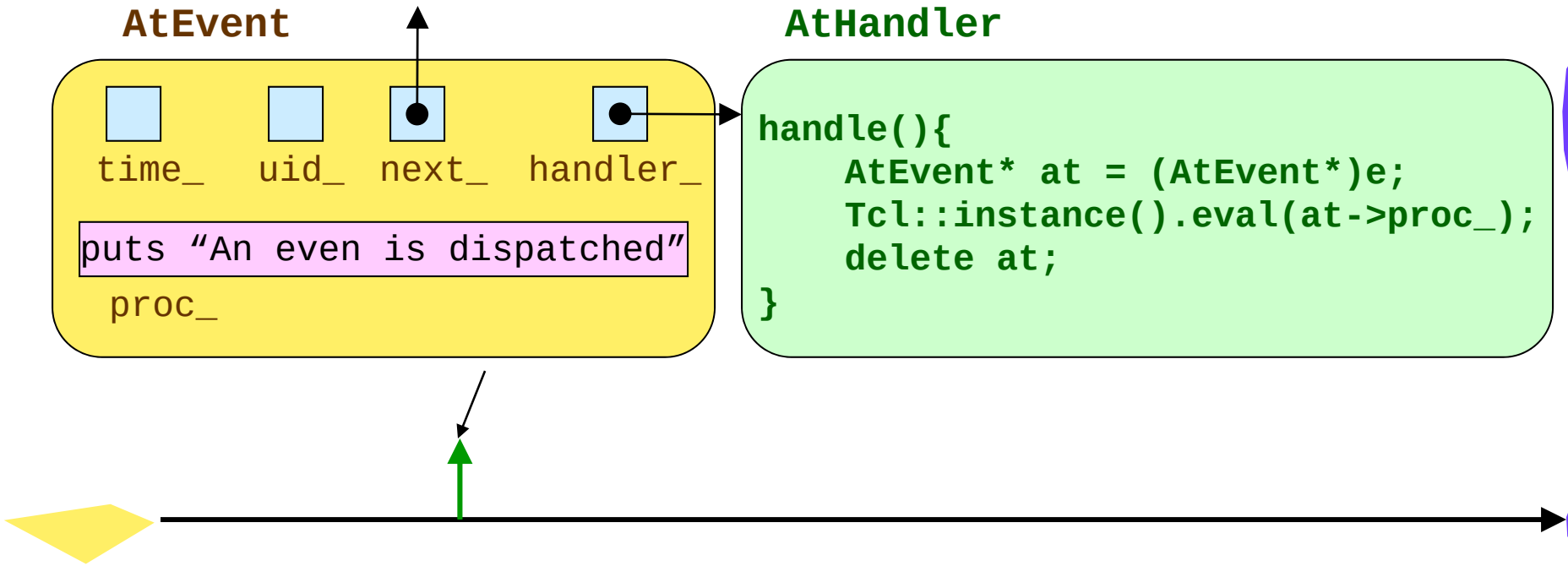
The Scheduler: Outline

- Overview
- C++ Class Scheduler
- Unique ID and Its Mechanism
- Scheduling and Dispatching Mechanism
- Null Events and Dummy Events

Scheduling-Dispatching Mechanism

- Example:

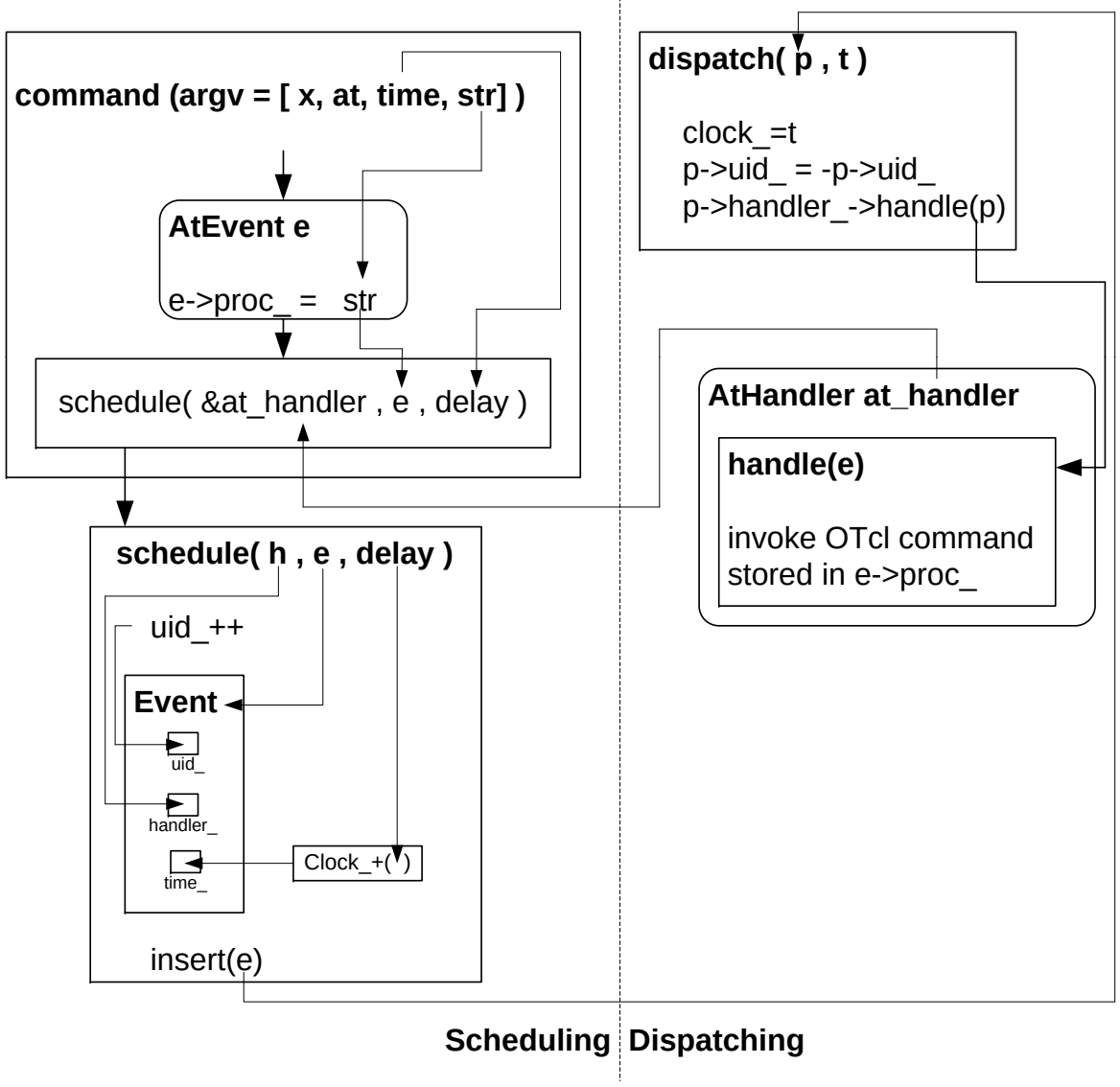
```
set ns [new Simulator]
$ns at 10 [puts "An event is dispatched"]
$ns run
```



Scheduling-Dispatching Mechanism

```
Scheduler::command(int argc, const char*const* argv)
{
      Tcl& tcl = Tcl::instance();
      if (argc == 4) {
         if (strcmp(argv[1], "at") == 0) {
                double delay, t = atof(argv[2]);
                const char* proc = argv[3];
               AtEvent* e = new AtEvent; int n = strlen(proc);
                e->proc_ = new char[n + 1];
                strcpy(e->proc_, proc);
                delay = t - clock();
                schedule(&at_handler, e, delay);
                return (TCL_OK);
         }
      }
      return (TclObject::command(argc, argv));
   }
```

Scheduling-Dispatching Mechanism



The Scheduler: Outline

- Overview
- C++ Class Scheduler
- Unique ID and Its Mechanism
- Scheduling and Dispatching Mechanism
- Null Events and Dummy Events

Null and Dummy Events Scheduling

- In general, we feed the event into the Scheduler.
- The event contains
  - Time where the event occurs, and
  - Ref. to an action taker (i.e., the handler)
- Example
  - Event = Packet
  - Time = Time where the packet is received
  - Default action = Receive a packet
  - Action taker = NsObject
- In some case, we the default action involves no event.
- E.g., Print a string after a certain delay
- What event would we feed to the function

`Scheduler::schedule(handler, event,delay)` ?

Q: delay = ?; handler = ?; event = ?

Null and Dummy Events Scheduling

- Null Event: set event = 0

```
Scheduler::schedule(handler,0,delay)
```

- Dummy Event:
  - A member variable whose type is Event
  - It does nothing but being placed in function

```
schedule(handler,dummy_event,delay)
```

Null and Dummy Events Scheduling

- Dummy event example: class `LinkDelay`

```
//~ns/link/delay.h
class LinkDelay : public Connector {
    ...
    Event intr_;
};


//~ns/link/delay.cc
void LinkDelay::recv(Packet* p, Handler* h)
{
    ...
    s.schedule(h, &intr_, txt);
}
```

Null and Dummy Events Scheduling

- Which one should we use? Null or Dummy?
- Null events
  - Simple, but no mechanism to preserve `uid_` conformance
  - You lose the scheduling-dispatching protection mechanism.
  - Suitable for simple cases
- Dummy events
  - Require a declaration in a class.
  - A bit more complicated, but will conform with NS2 scheduling-dispatching mechanism
  - Suitable for more complicated cases

Outline

- Recap: Discrete Event v.s. Time Driven
- Events and Handlers
- The Scheduler
- The Simulator
- Summary

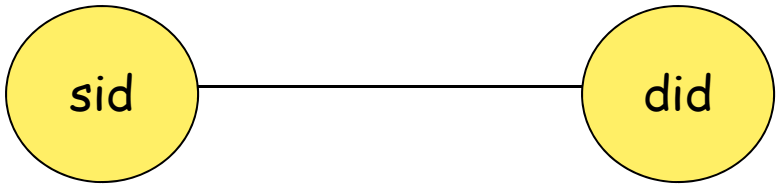
The Simulator

- Maintain assets which are shared among simulation objects
  - The schedulers ➔ Event scheduling
  - The null agent ➔ Packet destruction
  - Node reference ➔ All nodes
  - Link reference ➔ All links
  - Ref.to the routing component ➔ Routing
- It does not do the above functionalities.
- It only provide the ref. to the obj which does the above functionalities

Q:What is an advantage of putting the ref. to the Simulator?

The Simulator

- OTcl and C++ Classes `Simulator`
- OTcl Instvar
  - `scheduler_`: The schduler
  - `nullAgent_`: The packet destruction object
  - `Node_(<nodeid>)`: stores node objects
  - `link_(sid:did)`: stores link objects connecting two nodes
  - `routingTable_`: stores the routing component



C++ Class Simulator

```
//~ns/common/simulator.h
class Simulator : public TclObject {
public:
    static Simulator& instance() { return (*instance_); }
    Simulator() : nodelist_(NULL),
            rtobject_(NULL), nn_(0), size_(0) {}
    ...
private:
    ParentNode **nodelist_;
    RouteLogic *rtobject_;
    int nn_;
    int size_;
    static Simulator* instance_;
};
```

- Function `instance()`: Retrieve the static `Simulator instance_`.

Retrieving the Simulator Instance

- **Instproc** `instance{}`

```
//~ns/tcl/lib/ns-lib.tcl
Simulator proc instance {} {
    set ns [Simulator info instances]
    if { $ns != "" } {
        return $ns
    }
    ...
}
```

- Q: What does `info instances` do?
- Q: Can it return more than one Simulator instance? Why? If so, which one do we choose?

Running Simulation

- Creating a `Simulator` object

```
set $ns [new Simulator]
```

- OTcl constructor:

```
//~ns/tcl/lib/ns-lib.tcl
Simulator instproc init args {
    $self create_packetformat
    $self use-scheduler Calendar
    $self set nullAgent_ [new Agent/Null]
    $self set-address-format def
    eval $self next $args
}
```

- `$ns` is now a `Simulator` instance

Running Simulation

- Main instproc `run{}`: Start simulation

```
//~/ns/tcl/lib/ns-lib.tcl
Simulator instproc run  {
    [$self get-routelogic] configure
    $self instvar scheduler_ Node_ link_ started_
    set started_ 1
    foreach nn [array names Node_] {
        $Node_($nn) reset
    foreach qn [array names link_] {
        set q [$link_($qn) queue]
        $q reset
    }
    return [$scheduler_ run]
}
```

Running Simulation

- `Scheduler::run{}`

```
//~ns/common/scheduler.cc
void scheduler::run()
{
    instance_ = this;
    Event *p;
    while (!halted_ && (p = deque())) {
        dispatch(p, p->time_);
    }
}
```

- Keep executing events until
  - no more event or
  - the simulation is halted

Instprocs of Class Simulator

Instproc	Meaning
`now{}`	Retrieve the current simulation time.
`nullagent{}`	Retrieve the shared null agent.
`use-scheduler{type}`	Set the type of the Scheduler to be `<type>`.
`at{time stm}`	Execute the statement `<stm>` at `<time>` second.
`run{}`	Start the simulation.
`halt{}`	Terminate the simulation.
`cancel{e}`	Cancel the scheduled event `<e>`.

Outline

- Recap: Discrete Event v.s. Time Driven
- Events and Handlers
- The Scheduler
- The Simulator
- Summary

Summary

- NS2 Simulator is Event Driven
- Event
  - Unique ID + Time + Handler
  - Two derived classes: ( )
- Handlers
  - ( )
  - ( )

Summary

- Scheduler
  - schedule(.): ( )
  - dispatch(.): ( )
  - run(): ( )
- Event UID Dynamics
  - schedule() ➔ +,
  - dispatch() ➔ -

Summary

- Null event and Dummy Event
  - Purpose: ( )
  - Differences:
    - Null Event = ( )
    - Dummy Event = ( )
- Simulator
  - Maintain all common objects: Scheduler, null agent, nodes, links, and routing table
  - Start the simulation (e.g., "$ns run")