State Machines

15-494 Cognitive Robotics
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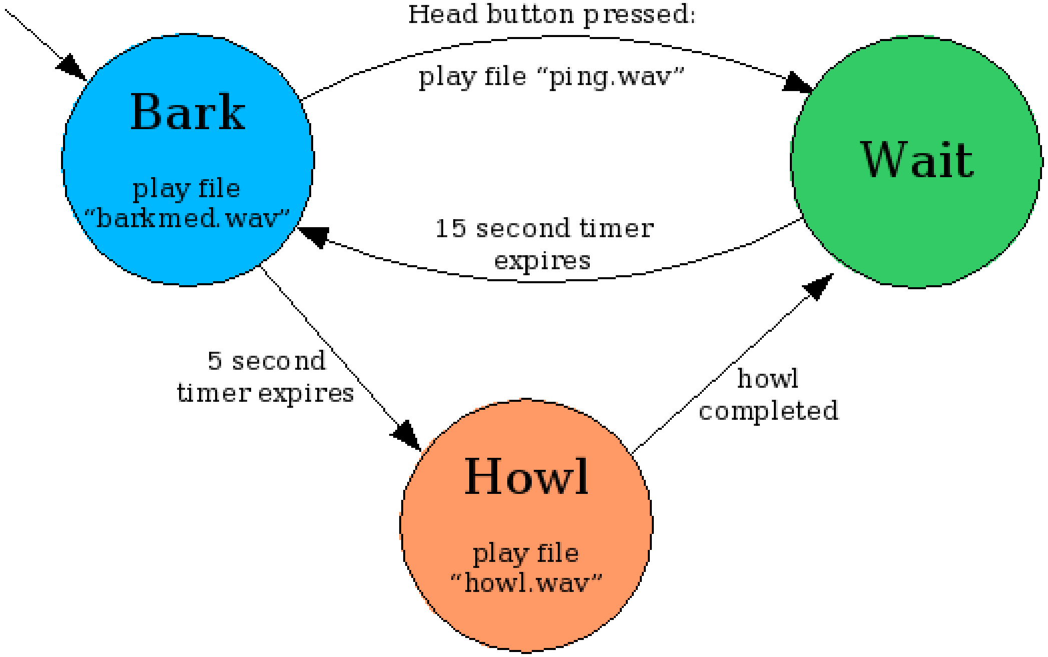
Robot Control Architectures

- State machines are the simplest and most widely used robot control architecture.
- Easy to implement; easy to understand.
- Not very powerful:
  - Action sequences must be laid out in advance, as a series of state nodes.
  - No dynamic planning.
  - Failure handling must be programmed explicitly.
- But a good place to start.

Basic Idea

- Robot moves from state to state.
- Each state has an associated action: *speak*, *move*, etc.
- Transitions triggered by sensory events or timers.

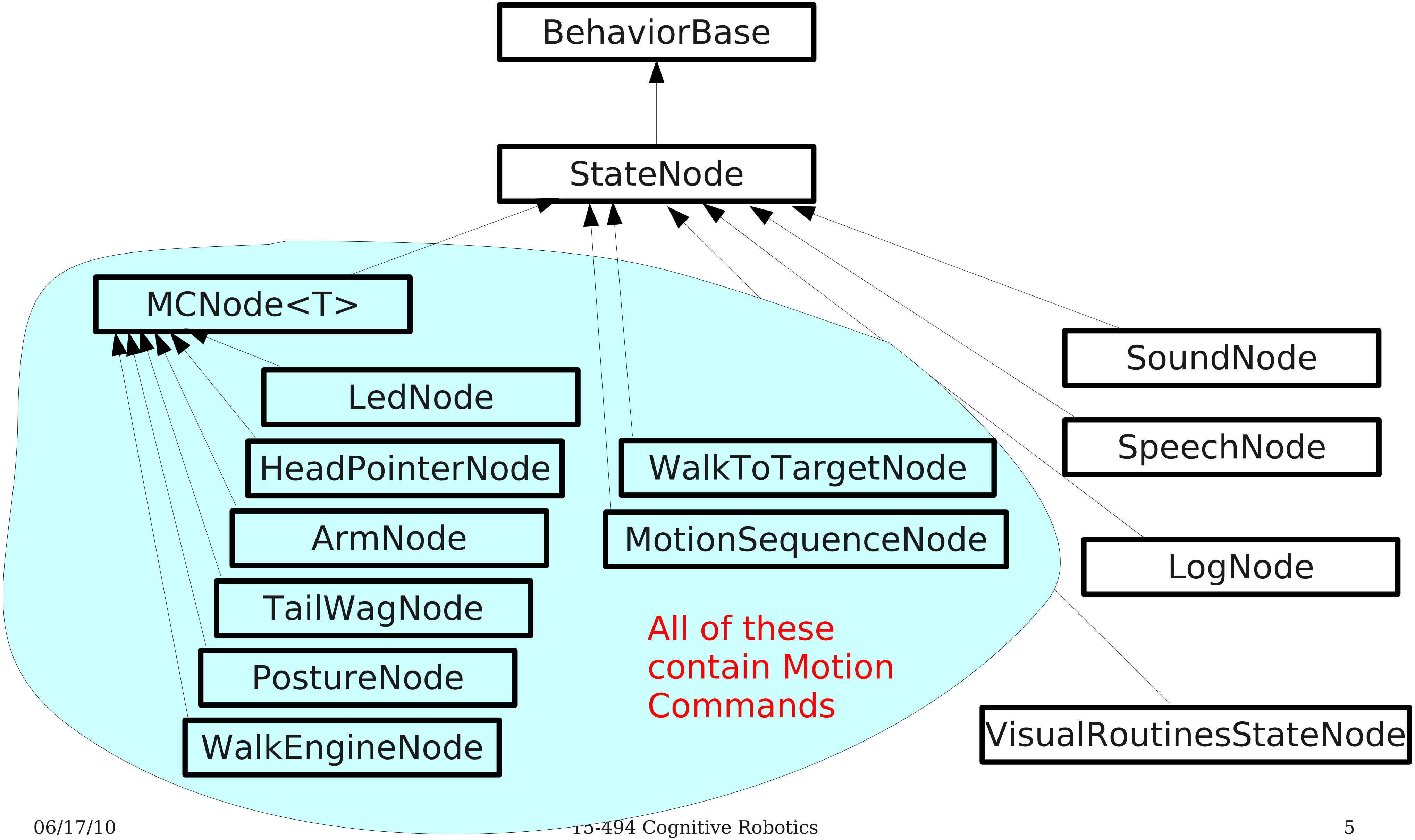


Tekkotsu State Nodes

- In Tekkotsu, state machine nodes are *behaviors*.
- StateNode is a child of BehaviorBase.
- To enter a state, call its start() method, which will call its DoStart() method if one has been supplied.
- To leave a state, call its stop() method.
- StateNodes can listen for and process events just like any other behavior.

Types of State Nodes

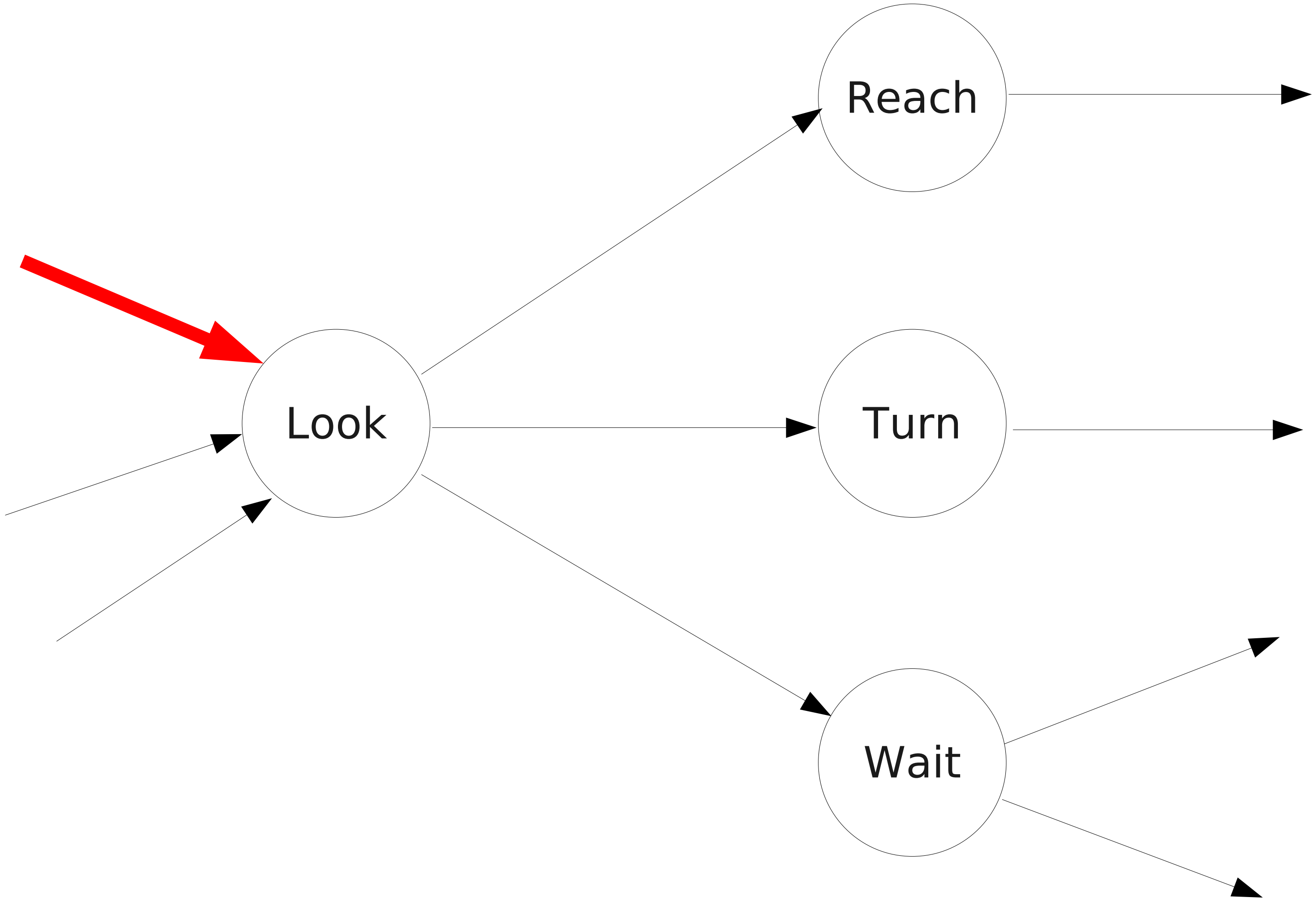
- State nodes encapsulate complex actions, such as creating and launching a motion command.



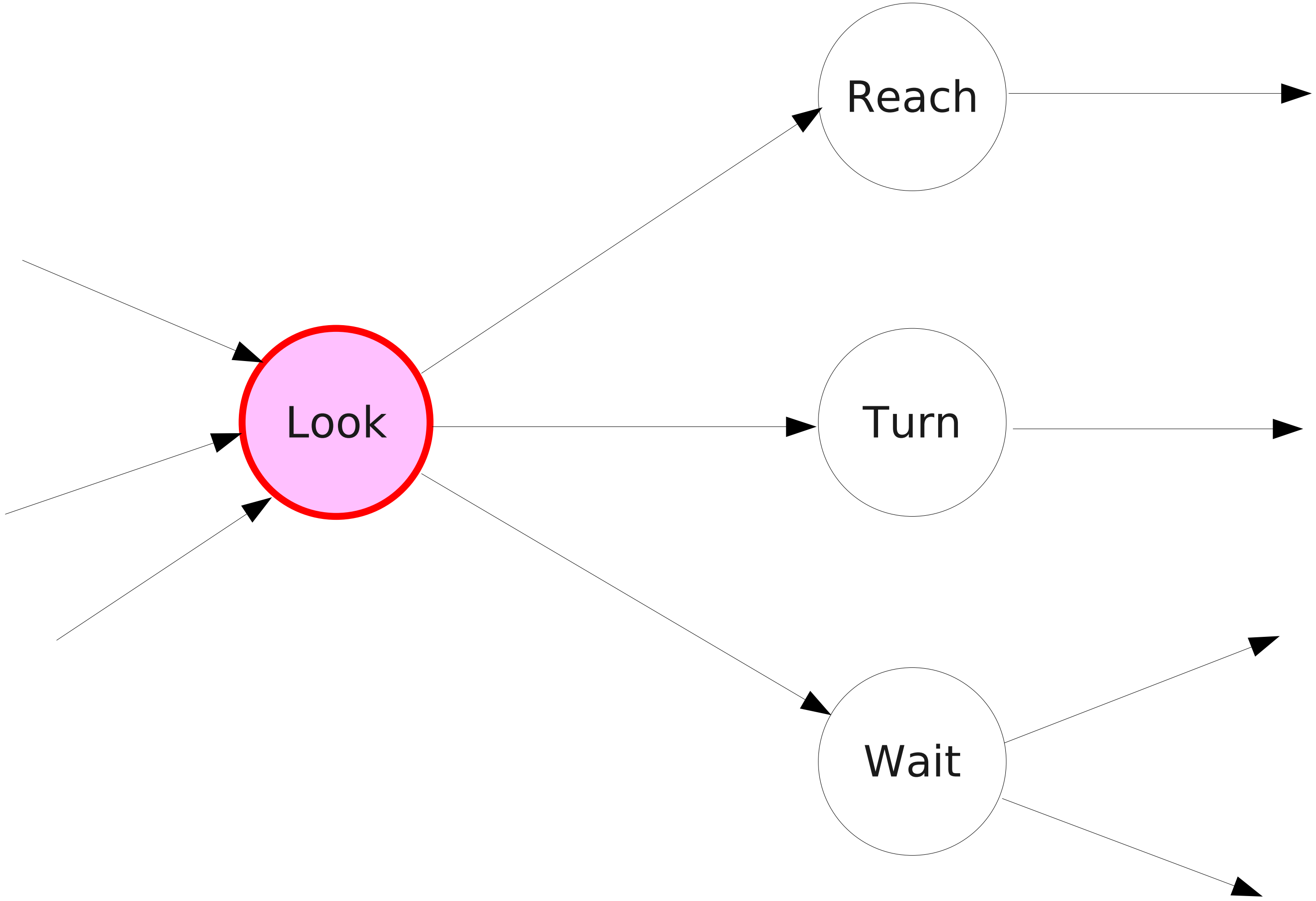
Transitions

- Transitions in Tekkotsu are also behaviors.
  - Transition and StateNode are *both* subclasses of BehaviorBase.
- A transition's start() is called whenever its source state node becomes active.
- Transitions listen for sensor, timer, or other events, and when their conditions are met, they *fire*.
- When a transition fires, it deactivates its source node(s) and then activates its destination node(s).

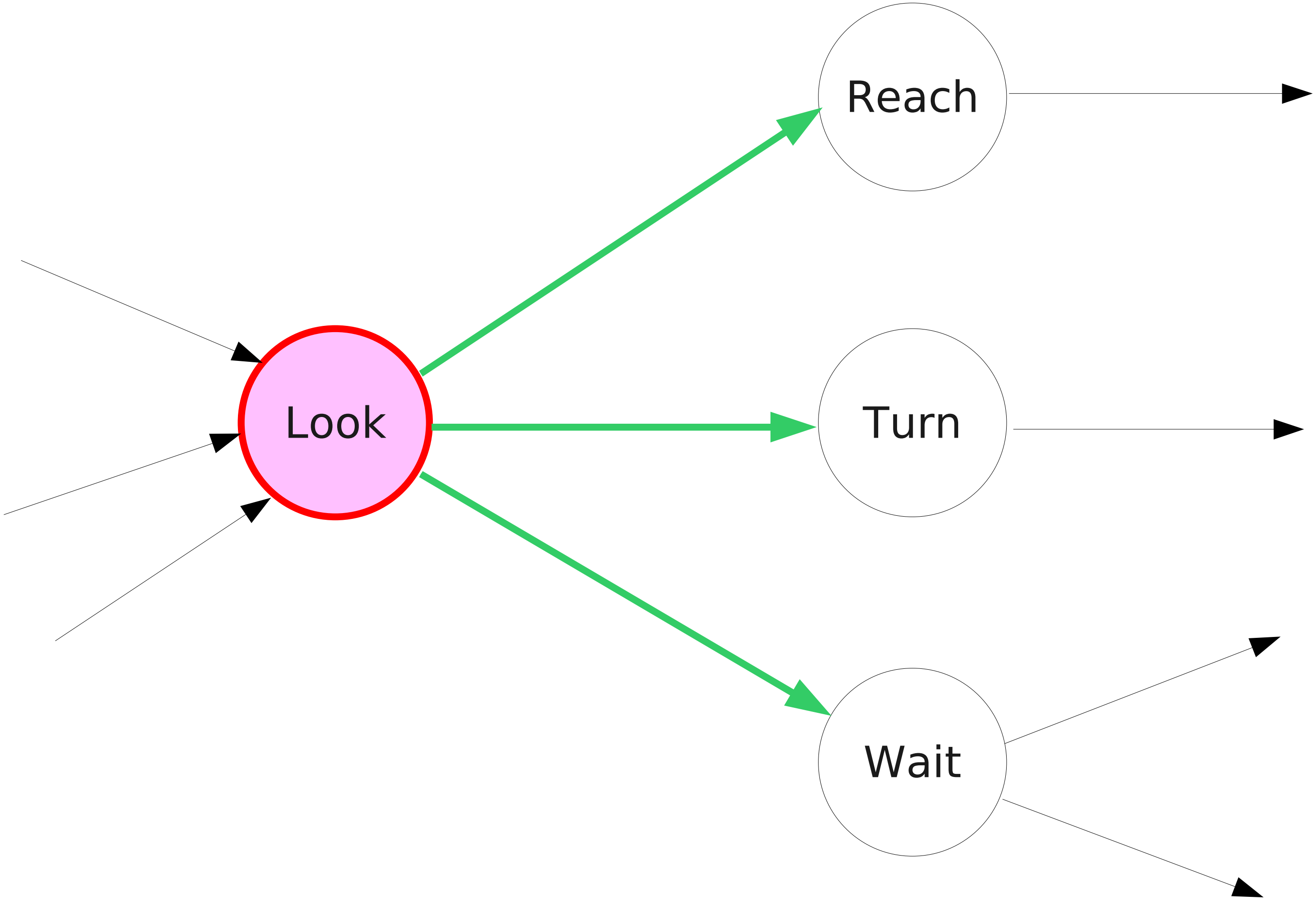
Transition firing activates state node Look.



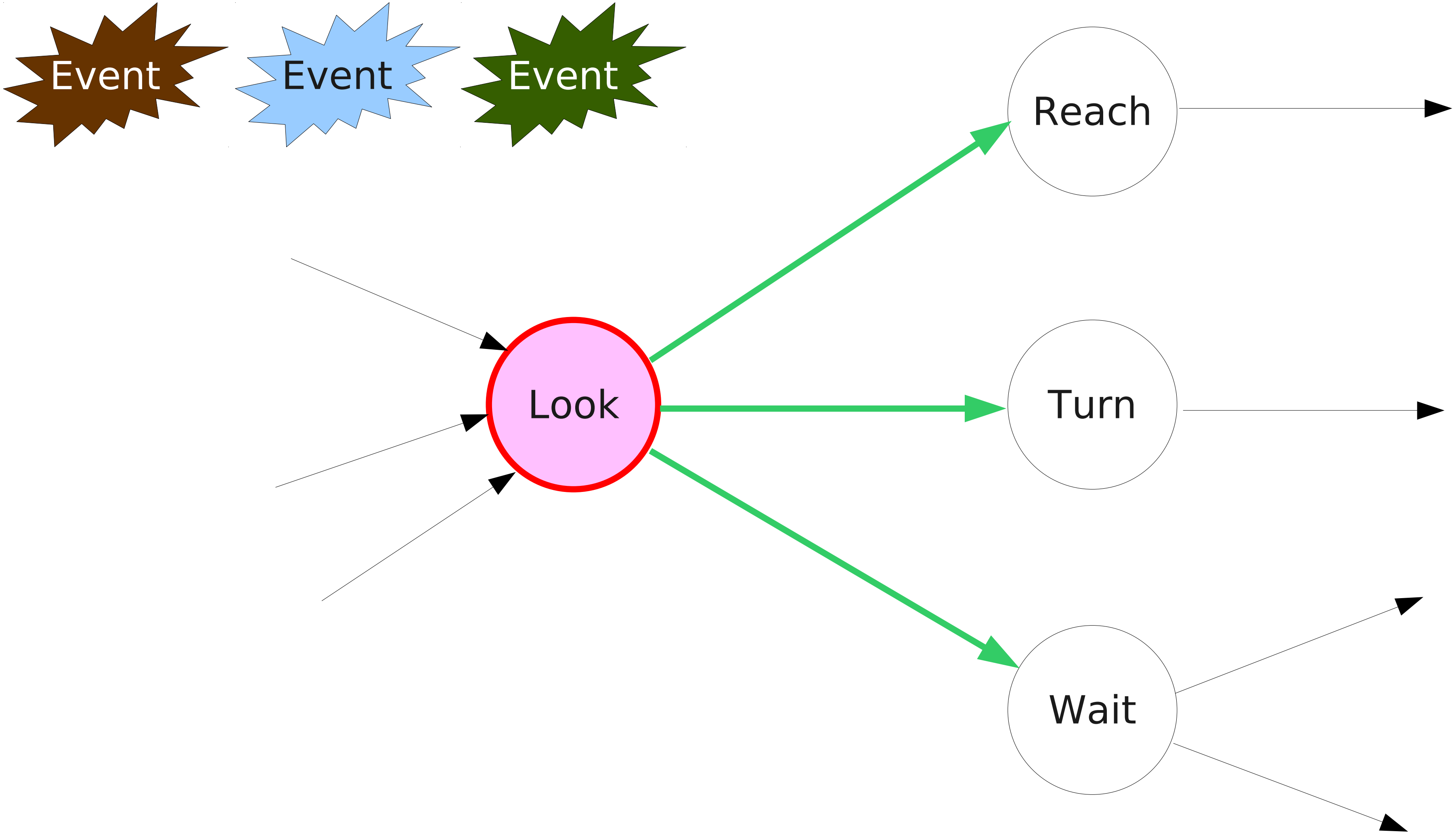
Look's start() calls StateNode::start().



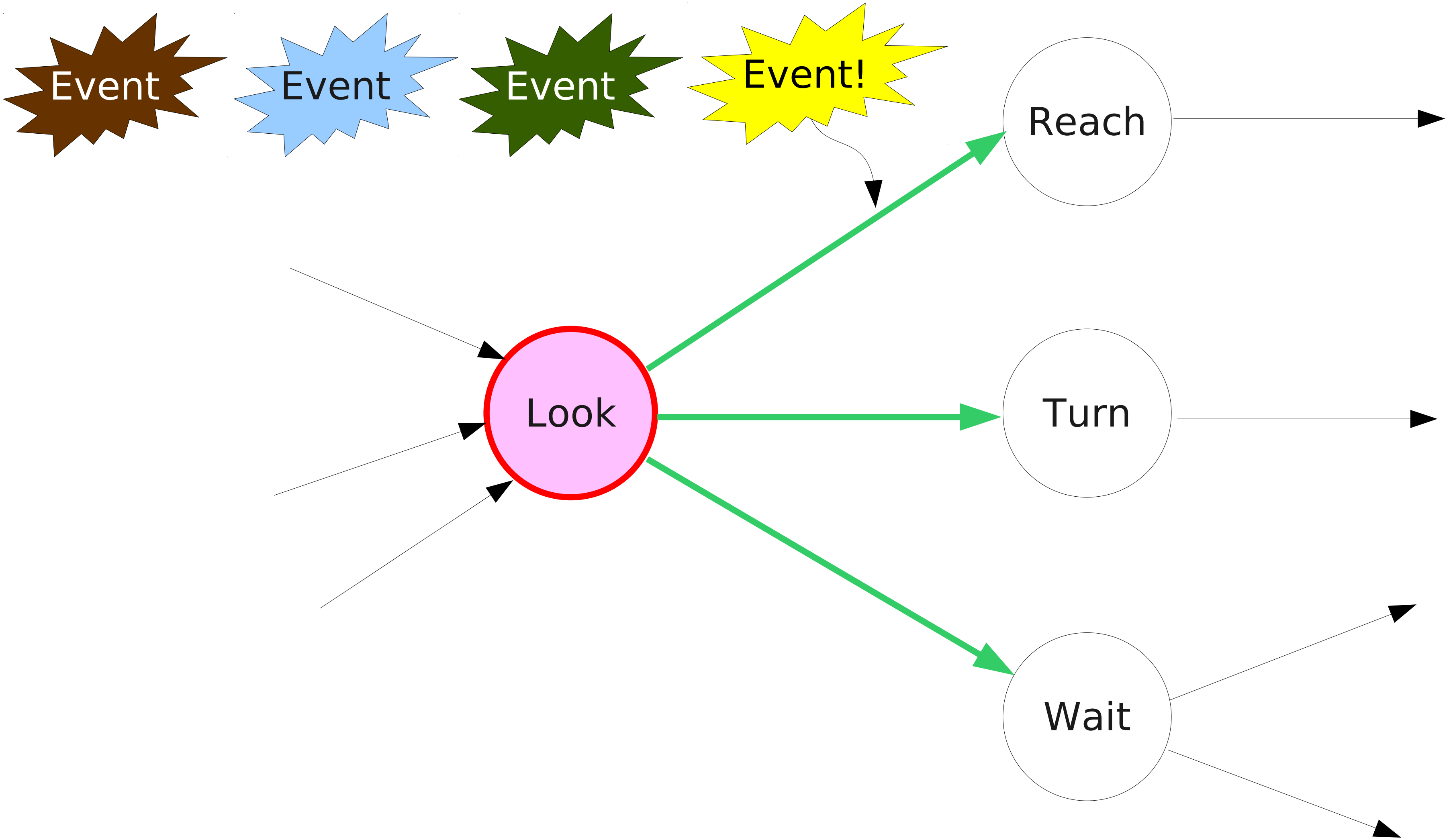
Outgoing transitions become active and begin listening for events.



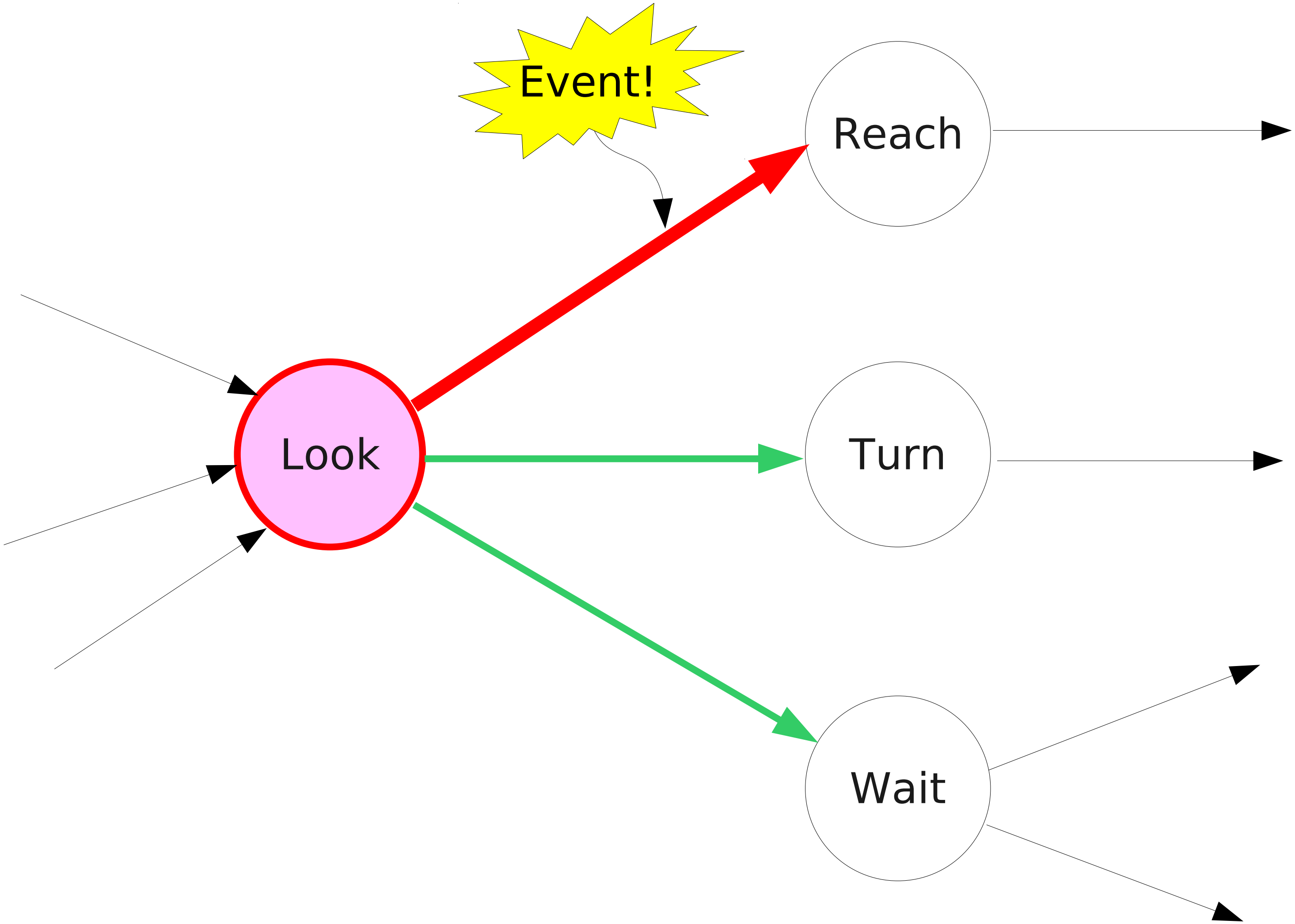
Random things happen....



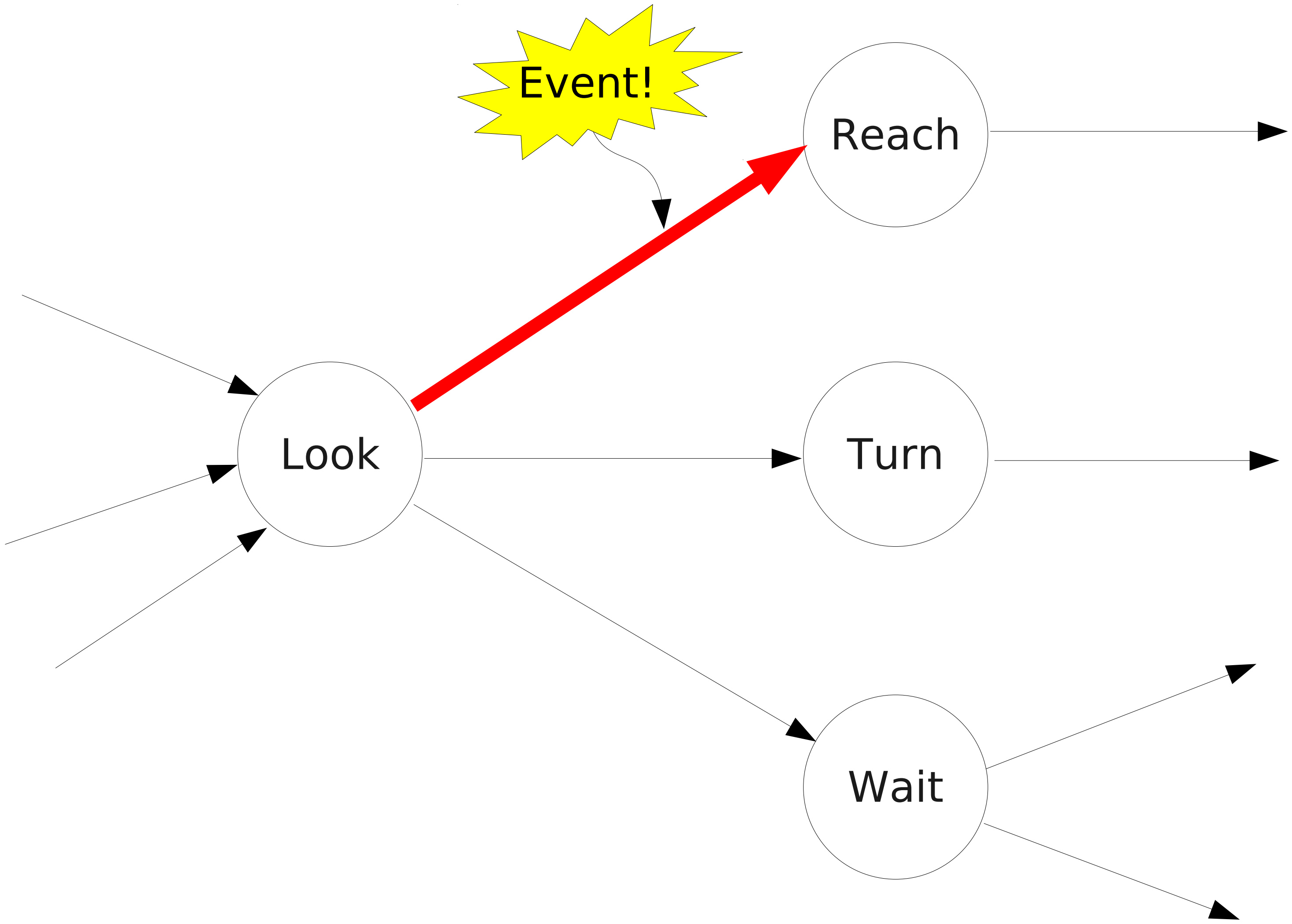
And then, something we've been looking for...



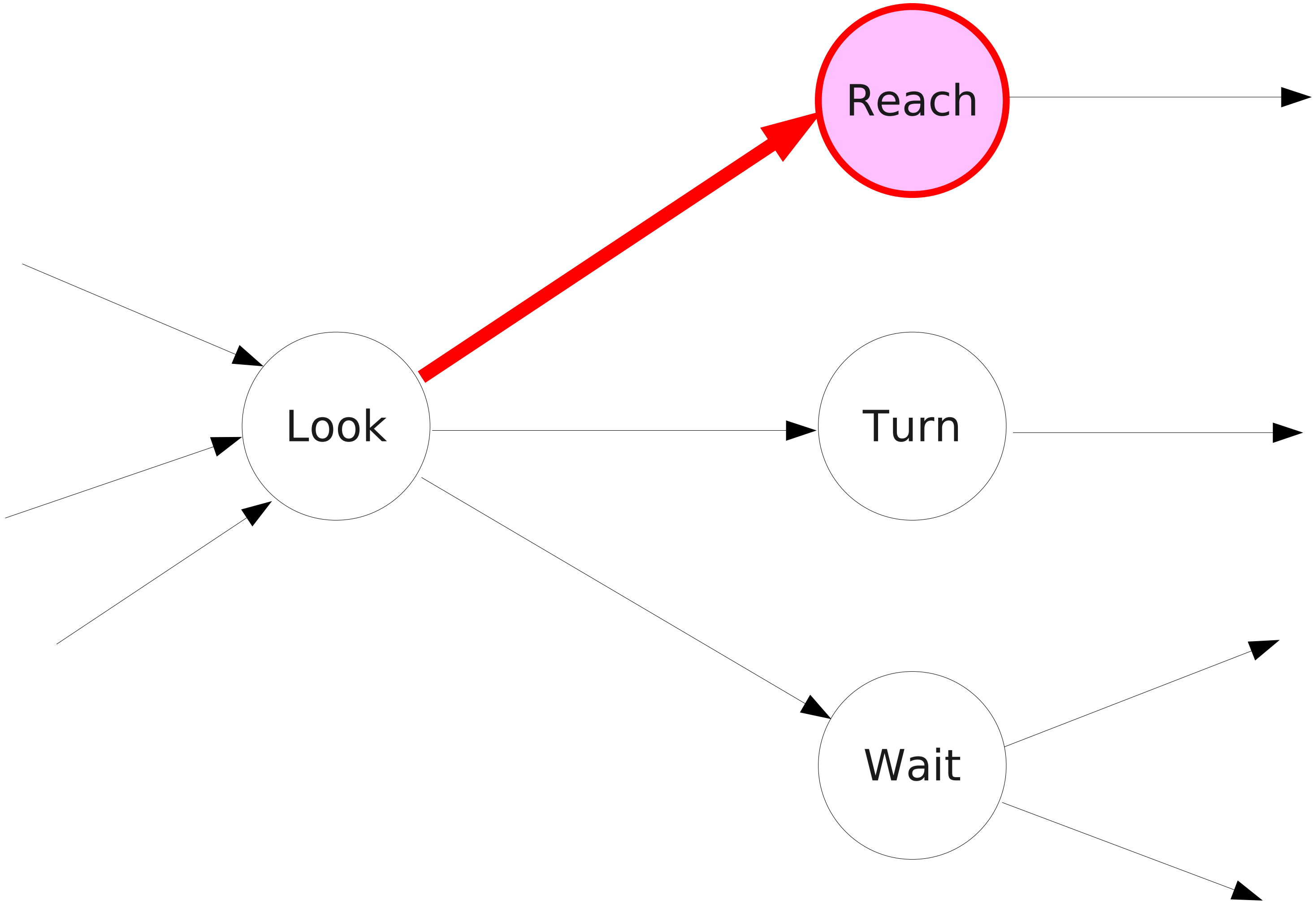
Transition decides to fire.



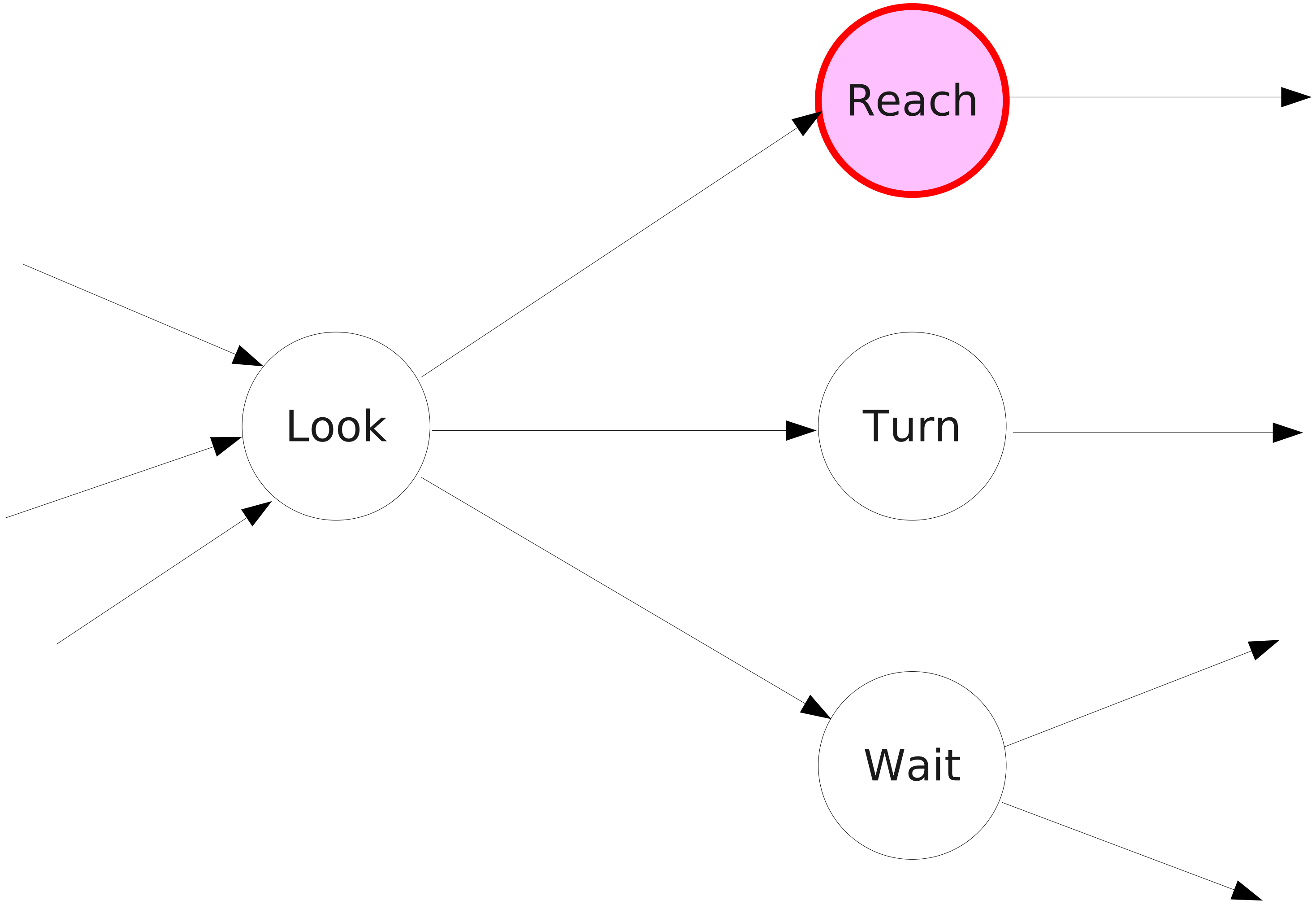
Transition deactivates the source node, Look.



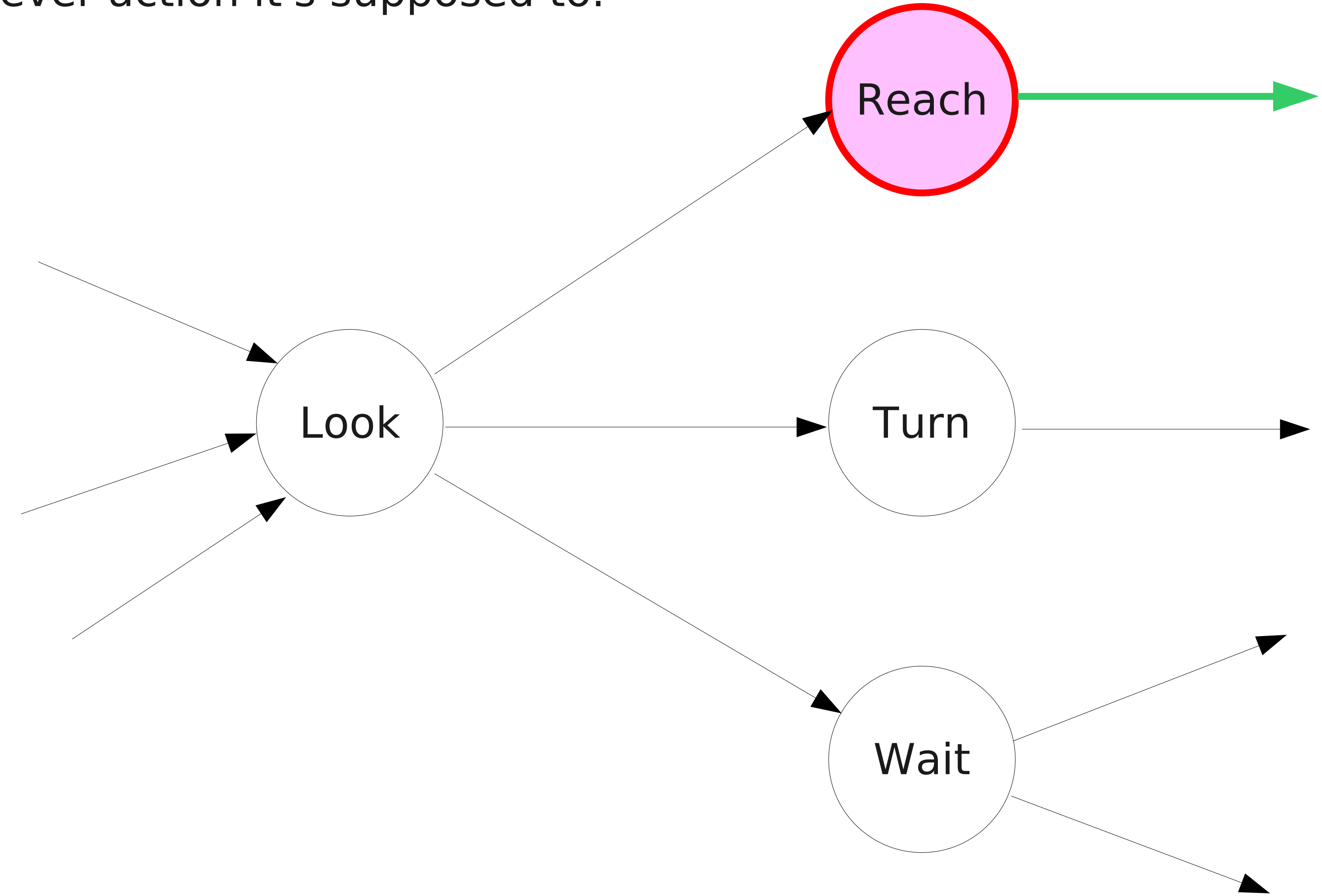
Transition activates the destination node, Reach.



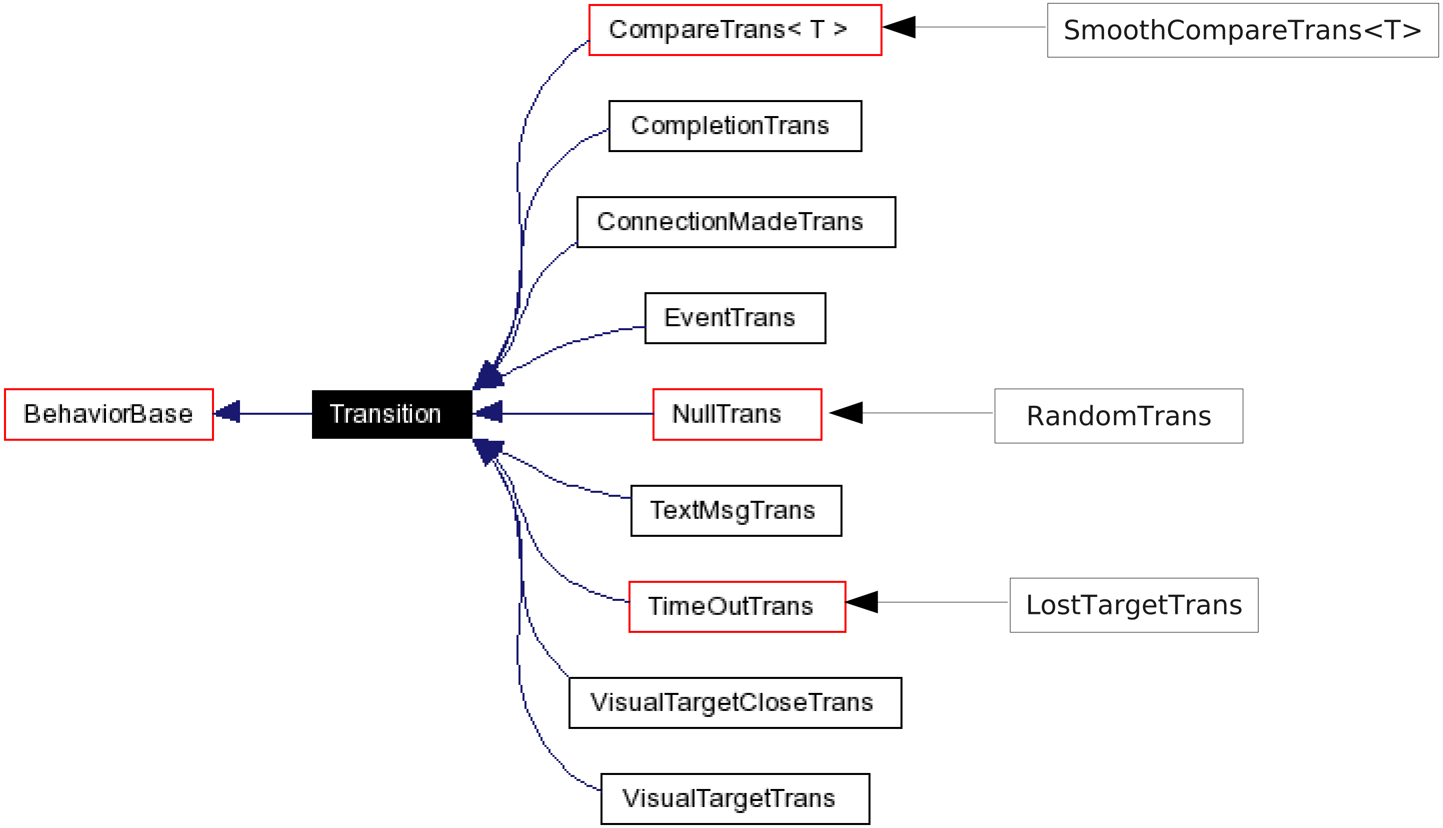
Transition deactivates.



Reach activates its outgoing transition, which starts listening for events as Reach performs whatever action it's supposed to.



Transition Types



State Machine Compiler

- Tekkotsu programmers don't normally write C++ code to build state machines one node or link at a time.
- They use a shorthand notation instead.
- The shorthand is turned into C++ by a state machine compiler.
- But to understand what the shorthand is doing, we need to build our first state machine by hand.

Programs As State Machines

Your program is the parent StateNode:

```
#include “Behaviors/StateMachine.h”

class BarkHowlBlinkBehavior : public StateNode {

public:
  BarkHowlBlinkBehavior() :
        StateNode("BarkHowlBlinkBehavior") {}
```

Setup and Teardown

- Programs must include a setup() function to construct the state machine as a child of the parent state node.

- setup() is called automatically the first time the parent's start() is called.

- A teardown() function is automatically provided to destroy the state machine. Called by ~StateNode().

Registering Nodes and Links

- Each node created by setup() must be registered with its parent using the addNode() method.

```
SoundNode *bark_node = new SoundNode("bark","barkmed.wav");
addNode(bark_node);
```

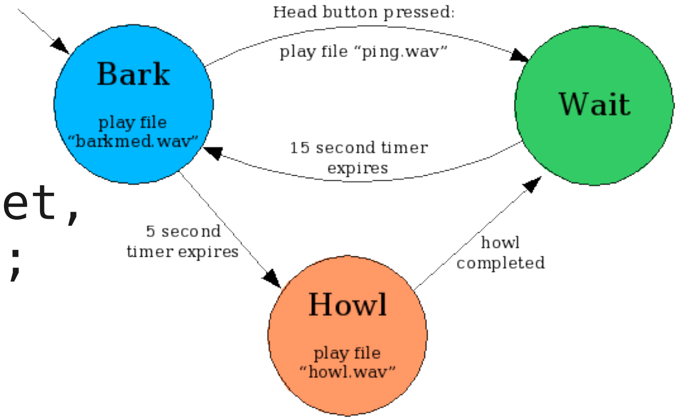
- Transitions are registered with their source nodes via the source node's addTransition() method.

```
bark_node->addTransition(new TimeOutTrans(howl_node,5000));
```

- The variable startnode must be set to point to the starting node of the state machine.

Setup Example

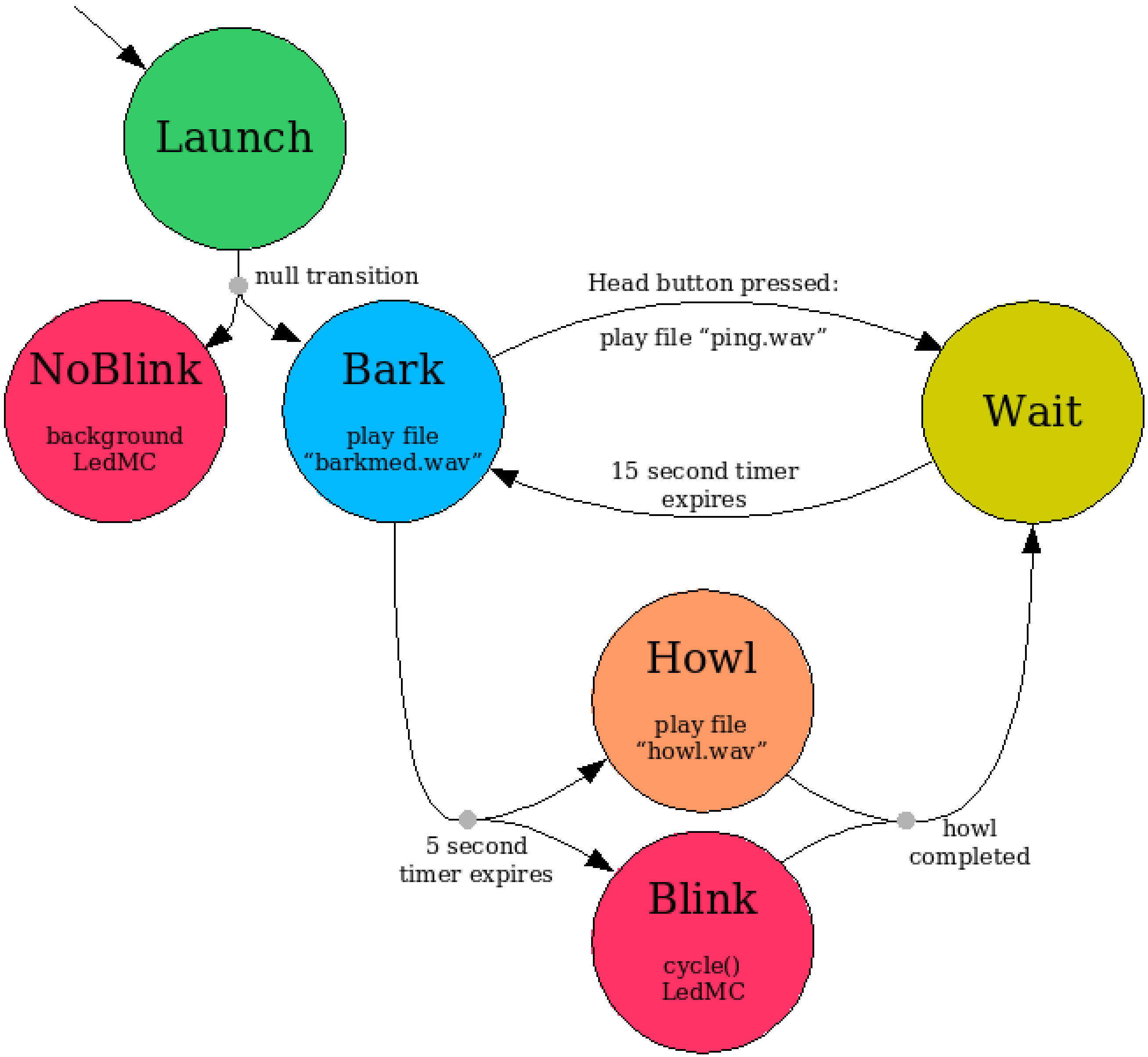
```
virtual void setup() {

    SoundNode *bark_node = new SoundNode("bark","barkmed.wav");
    SoundNode *howl_node = new SoundNode("howl","howl.wav");
    StateNode *wait_node = new StateNode("wait");
    addNode(bark_node); addNode(howl_node); addNode(wait_node);

    EventTrans *btrans =
      new EventTrans(wait_node,
                     EventBase::buttonEGID,
                     ChiaraInfo::GreenButOffset,
                     EventBase::activateETID);
    btrans->setSound("ping.wav");
    bark_node->addTransition(btrans);


    howl_node->addTransition(new CompletionTrans(wait_node));
    wait_node->addTransition(new TimeOutTrans(bark_node,15000));

    startnode = bark_node;
  }
```



Extensions to the Basic Formalism

- Extension 1: multi-states (parallelism).
  - Several states can be active at once.
  - Provides for parallel processing (but coroutines, not threads).
- Extension 2: hierarchical structure.
  - State machines can nest inside other state machines.
- Extension 3: message passing.
  - When a state posts an event that triggers a transition, it can include a message that will be passed to the destination state.
  - This makes state transitions resemble procedure calls.

Multi-State Machines

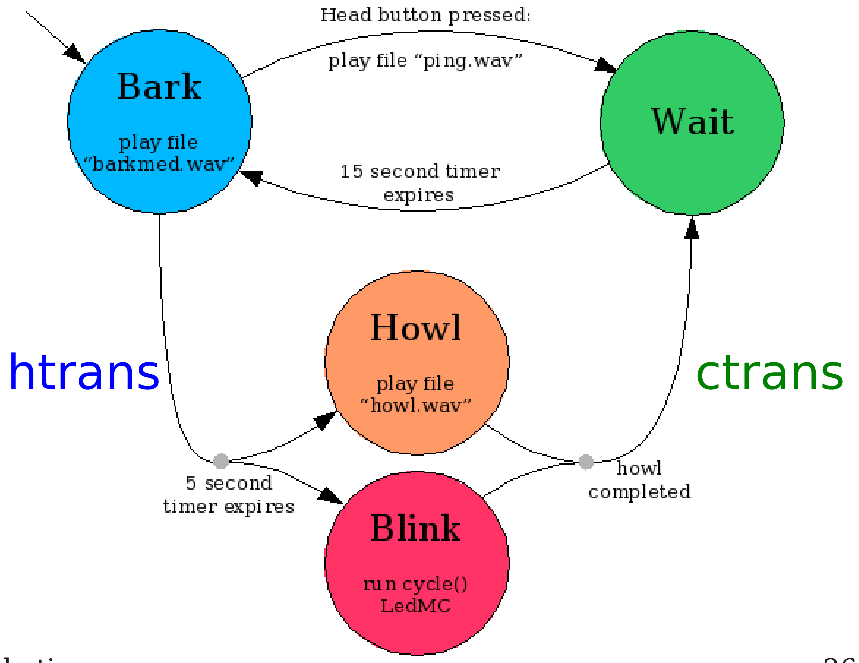


Blink Using LedEngine::cycle()

- Blink uses a motion command called LedMC, which is a child of LedEngine.
- The LedEngine::cycle() method never completes.
- When the howl completes, we want to leave both the howl state and the blink state.
- We can do this by telling CompletionTrans that only one of its source nodes needs to signal a completion in order for the transition to fire.
- When it does fire, it will deactivate both source nodes.

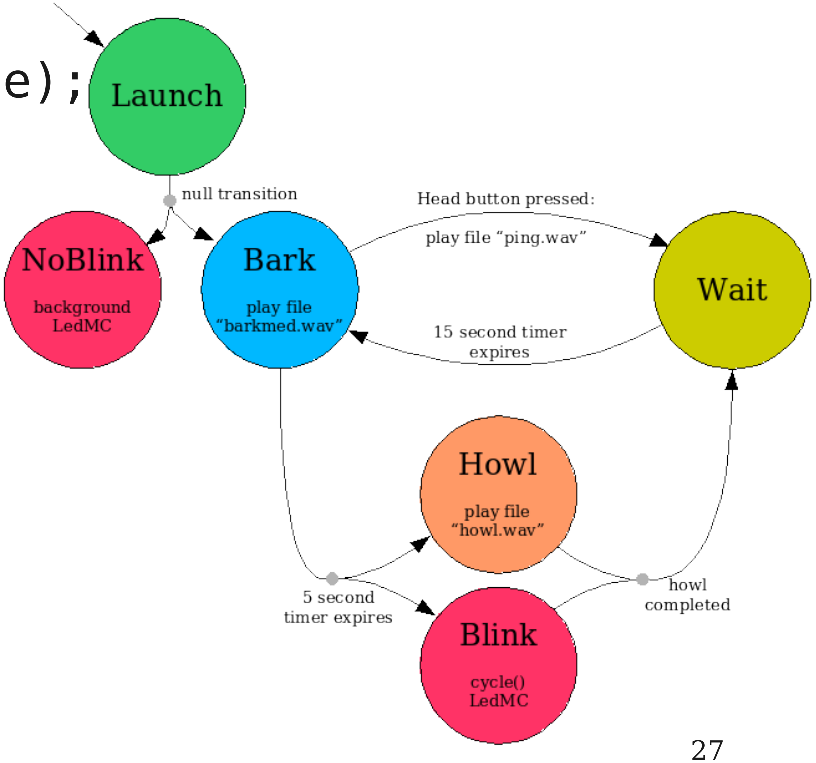
Setting Up the Blink

```
LedNode *blink_node = new LedNode(“blink”);
addNode(blink_node);
blink_node->getMC()->cycle(RobotInfo::AllLEDMask,1500,1.0);

TimeOutTrans *htrans = new TimeOutTrans(howl_node,5000);
htrans->addDestination(blink_node);
bark_node->addTransition(htrans);

CompletionTrans *ctrans = new CompletionTrans(wait_node,1);
howl_node->addTransition(ctrans);
blink_node->addTransition(ctrans);
```



Cleaning Up the Blink: Turn The LEDs Off

```
LedNode *noblink = new LedNode(“noblink”);

noblink->getMC()->set(RobotInfo::AllLEDMask, 0.0);
noblink->setPriority(MotionManager::kBackgroundPriority);

StateNode *launcher = new Statenode(“launcher”);

NullTrans *ntrans = new NullTrans(bark_node);
ntrans->addDestination(noblink);

launcher->addTransition(ntrans);

startnode = launcher;
```



Shorthand Notation

```
bark: SoundNode($,”barkmed.wav”)

howl: SoundNode($,”howl.wav”)

wait: StateNode


bark =T(5000)=> howl


bark =B(RobotInfo::GreenButOffset)=> wait
```

Shorthand Notation

- Node definition:

  nodename: NodeClass(*constructor_args*)[*initializers*]

- Transition, short form examples:

  ```
  source =C=> target
  source =T(n)=> target
  source =E(g,s,t)=> target
  ```

- Transition, long form:

  source >== transname:
  TransitionClass*(constructor_args)*[*initializers*] ==> *targetnode*

- Multiple sources/targets:

  source >==Transition==> {targ1name, targ2name, …}

$ and $$

- *Use $ to refer to the name of the current node, e.g., these are equivalent:*

foo: Statenode	---
foo: StateNode($)	*bar: SoundNode($,”howl.wav”)*
foo: StateNode(“foo”)	*bar: SoundNode(“bar”,”howl.wav”)*

Must be present to allow second argument

- *In long form, use $$ to refer to the destination node of a transition, e.g., these are equivalent:*

foo >==EventTrans($$,EventBase::buttonEGID)==> bar

foo >==EventTrans(bar,EventBase::buttonEGID)==> bar

More Shorthand

>==NullTrans==>	=N=>
>==CompletionTrans==>	=C=>
>==CompletionTrans($,$$,n)==>	=C(n)=>
>==TimeoutTrans($,$$,t)==>	=T(t)=>
>==EventTrans($,$$,g,s,t)==>	=E(g,s,t)=>
>== EventTrans($,$$, EventBase::buttonEGID,s) ==>	=B(s)=>
>== TextMsgTrans($,$$,str)==>	=TM(str)=>
>==RandomTrans==>	=RND=>
>==SignalTrans<T>($,$$) ==>	=S<T>=>
>==SignalTrans<T>($,$$,v)==>	=S<T>(v)=>
>==SignalTrans<bool>($,$$,false)==>	=F=>

file: BarkHowlBlinkBehavior.cc.fsm

```
  virtual void setup() {
#statemachine
  startnode:StateNode =N=> {noblink, bark}

  noblink: LedNode
[setPriority(MotionManager::kBackgroundPriority);
                  getMC()->set(RobotInfo::FaceLEDMask,0.0)]

  bark: SoundNode($,"barkmed.wav")
          =B(GreenButOffset)[setSound("ping.wav")]=> wait

  wait: StateNode =T(15000)=> bark

  bark =T(5000)=> {howl, blink}

  howl: SoundNode($,"howl.wav")

  blink: LedNode [getMC()->cycle(RobotInfo::AllLEDMask, 1500, 1.0)]

  {howl, blink} =C(1)=> wait
#endstatemachine

} // end of setup()
```

```
#nodeclass MyMachine
  #shortnodeclass Greet : StateNode
  virtual void doStart() {
    cout << “Hello there!” << endl;
  }

  #shortnodeclass Sendoff : StateNode
  virtual void doStart() {
    cout << “So long!” << endl;
  }

  virtual void setup() {
    #statemachine
      startnode: Greet =T(5000)=> Sendoff
    #endstatemachine
  }
#endnodeclass
```

Compiling Your FSM

- The Makefile looks for files with names of form *.fsm and automatically runs them through the state machine compiler, called “stateparser”.
- BarkHowlBlinkBehavior.cc.fsm generates a pure C++ file called BarkHowlBlinkBehavior-fsm.cc.
- The .cc file is stored in:

  ~/project/build/PLATFORM_LOCAL/TARGET_*xxx*/

- You can run the stateparser directly:

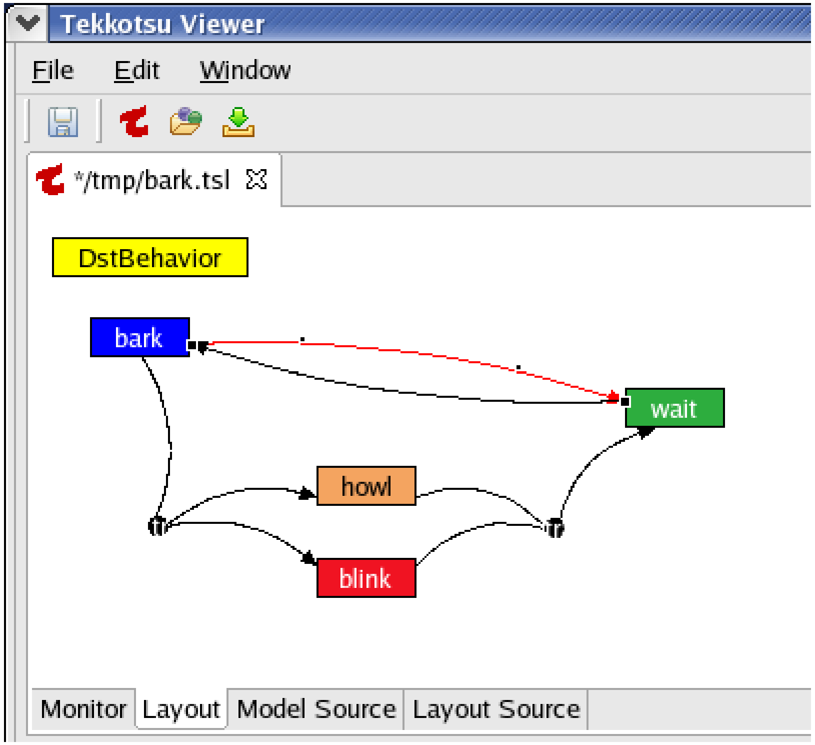
```
Tekkotsu/tools/stateparser  BarkHowlBlinkBehavior.cc.fsm  –
```

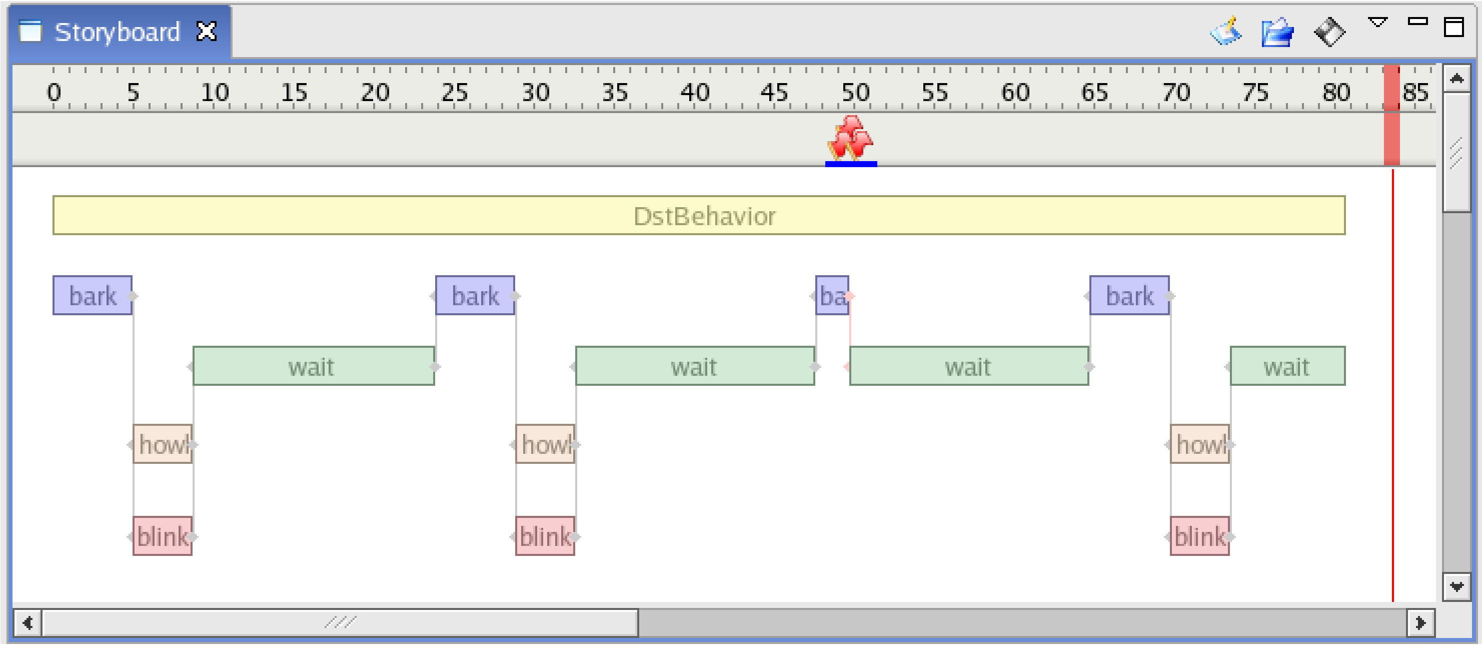
State Machine Events

- Entering or leaving a state generates a stateMachineEGID event.
  - activateETID for entering
  - deactivateETID for leaving
- Firing of a transition generates a stateTransitionEGID event.
- SignalTrans looks for a stateSignalEGID event
- You can use the Tekkotsu Event Logger to monitor these events:

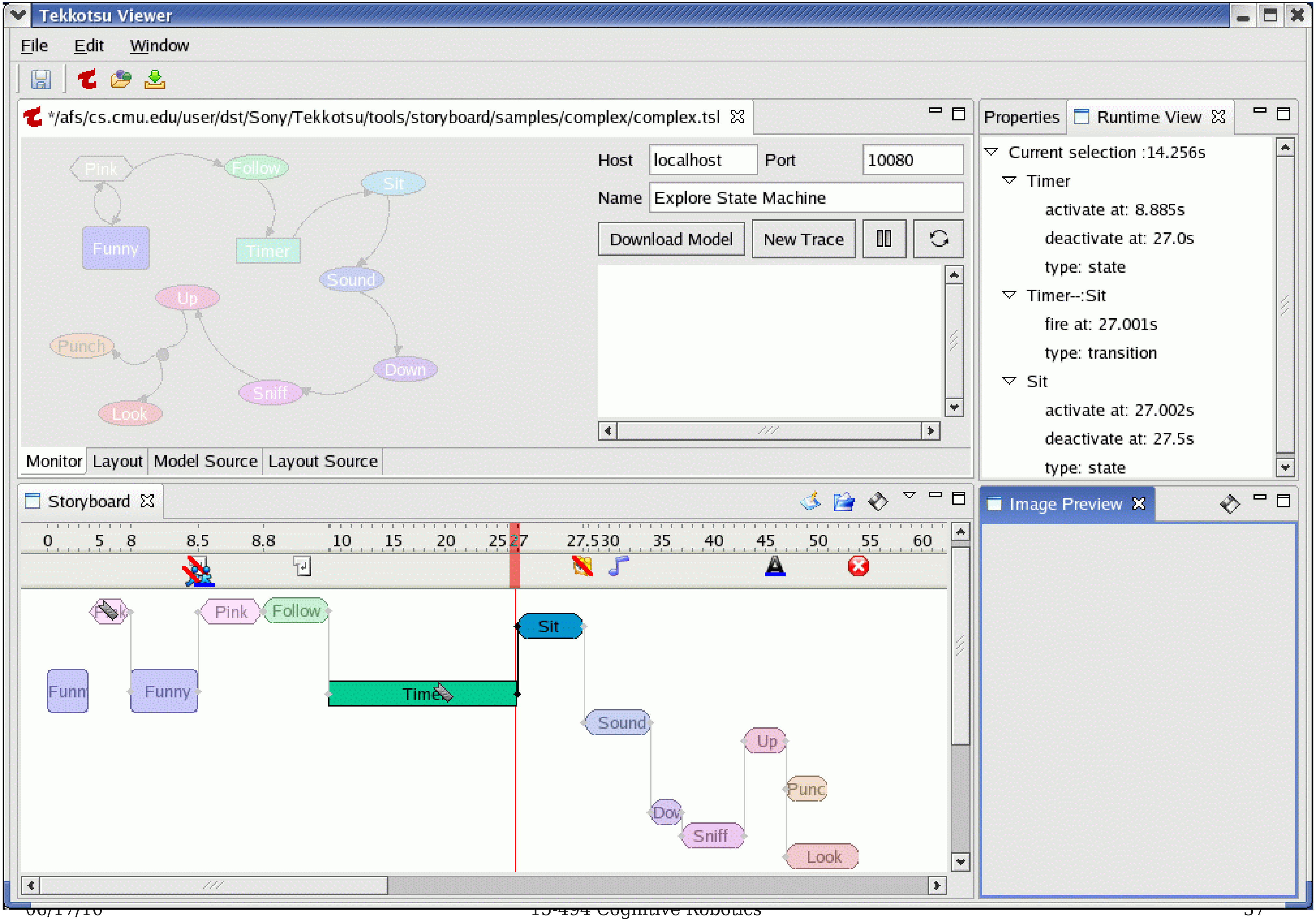
  Root Control > Status Reports > Event Logger

Storyboard Tool: State Machine Layout





Storyboard Tool: Storyboard Display



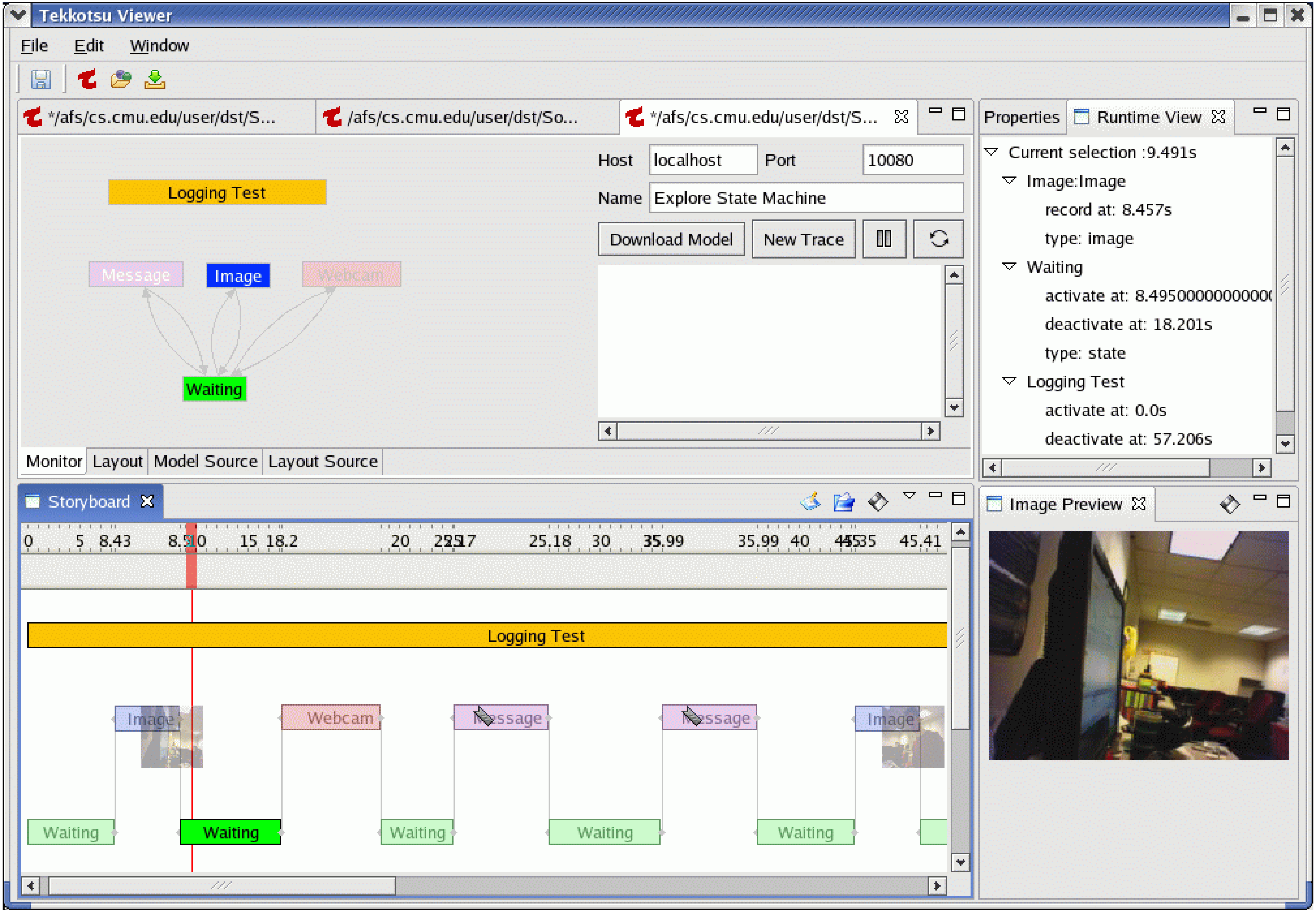
Tekkotsu Viewer

*/afs/cs.cmu.edu/user/dst/Sony/Tekkotsu/tools/storyboard/samples/complex/complex.tsl

Host: localhost
Port: 10080
Name: Explore State Machine

- Current selection :14.256s
  - Timer
    - activate at: 8.885s
    - deactivate at: 27.0s
    - type: state
  - Timer--:Sit
    - fire at: 27.001s
    - type: transition
  - Sit
    - activate at: 27.002s
    - deactivate at: 27.5s
    - type: state

Storyboard Tool: Snapshots



Host localhost Port 10080

Name Explore State Machine

- Current selection :9.491s
  - Image:Image
    - record at: 8.457s
    - type: image
  - Waiting
    - activate at: 8.49500000000000
    - deactivate at: 18.201s
    - type: state
  - Logging Test
    - activate at: 0.0s
    - deactivate at: 57.206s