State Machines

15-494/694 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.
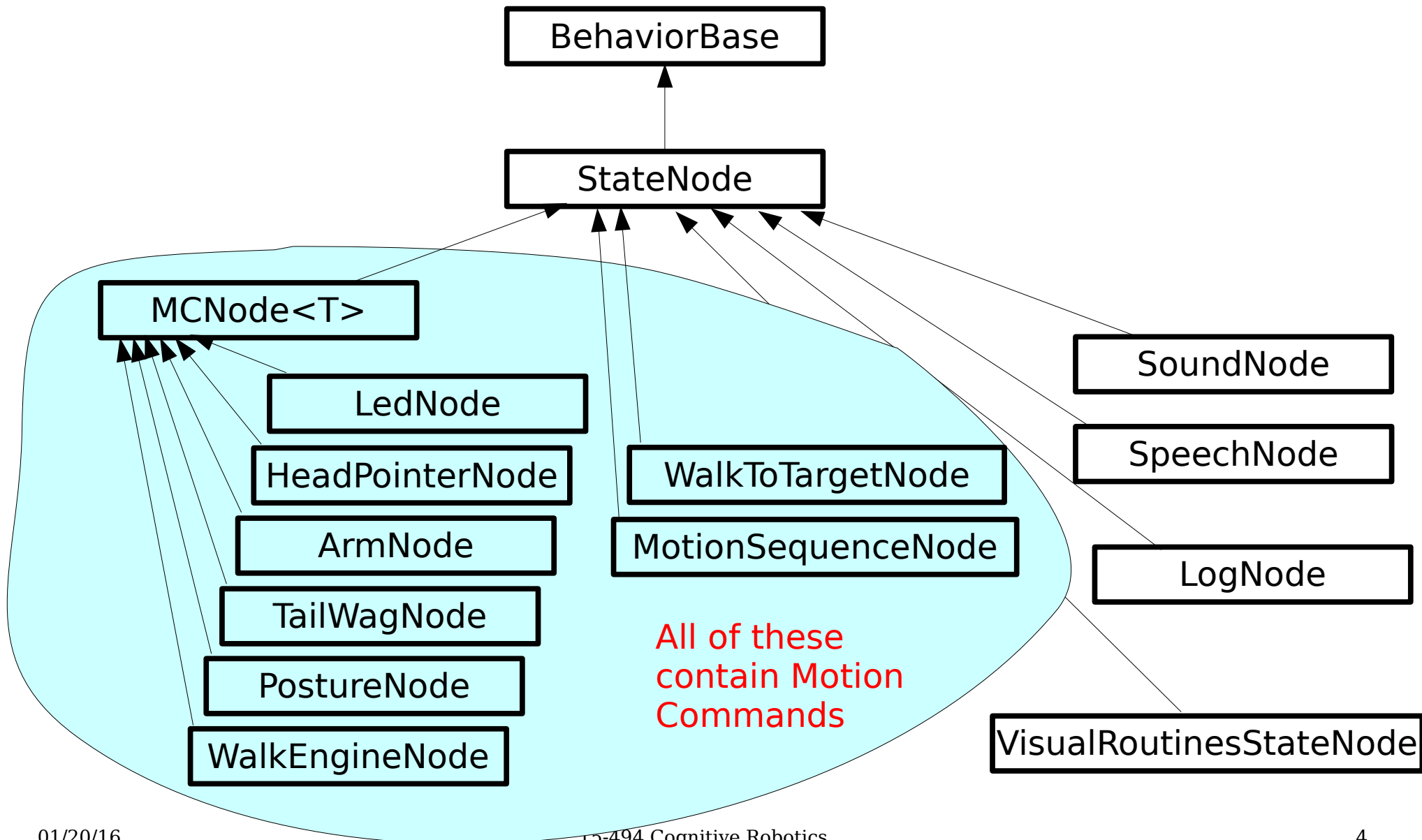
- But a good place to start.

Basic Idea

- Robot moves from state to state.

- Each state has an associated action: *speak*, *move*, etc.
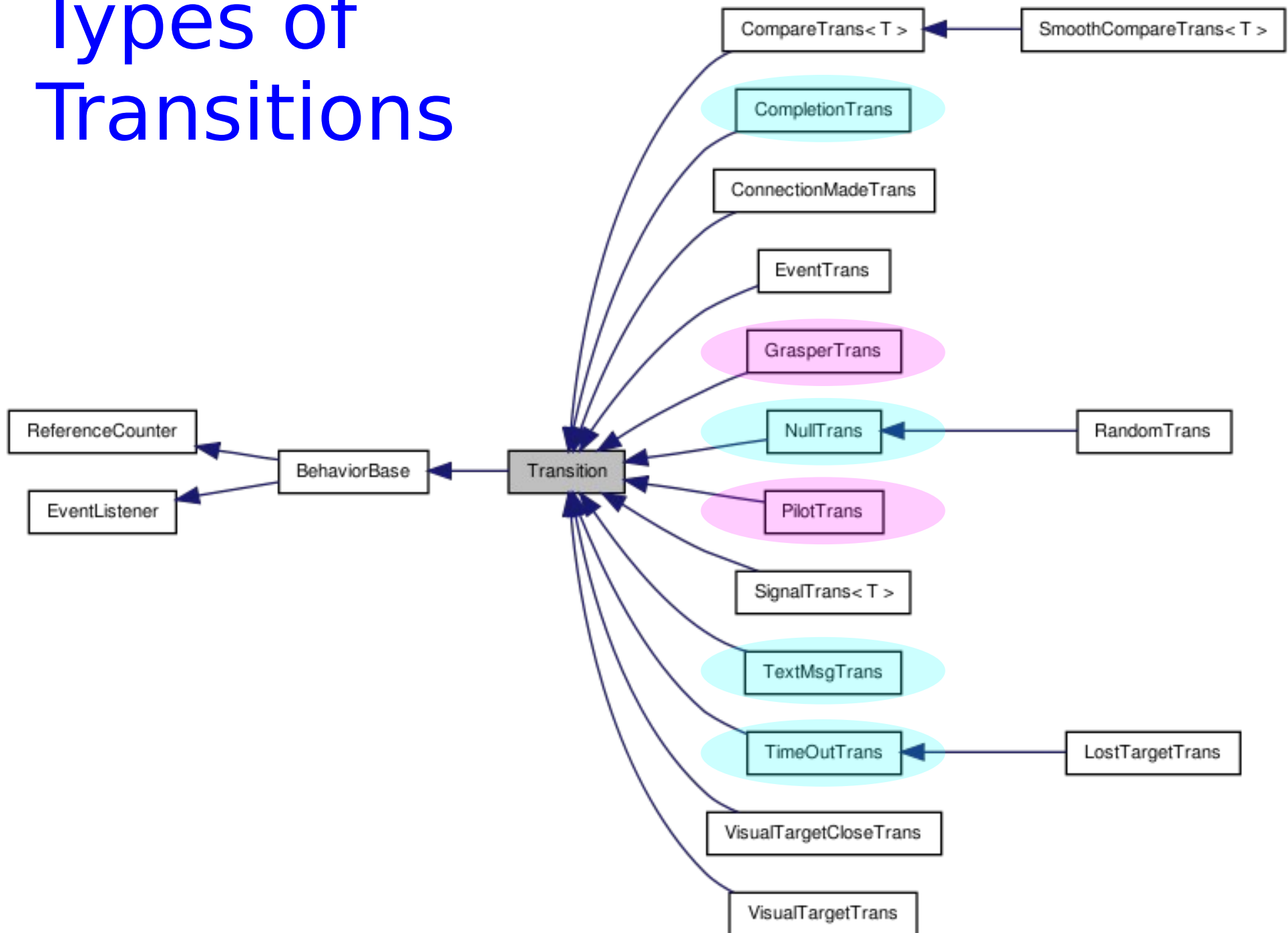
- Transitions triggered by sensory events or timers.
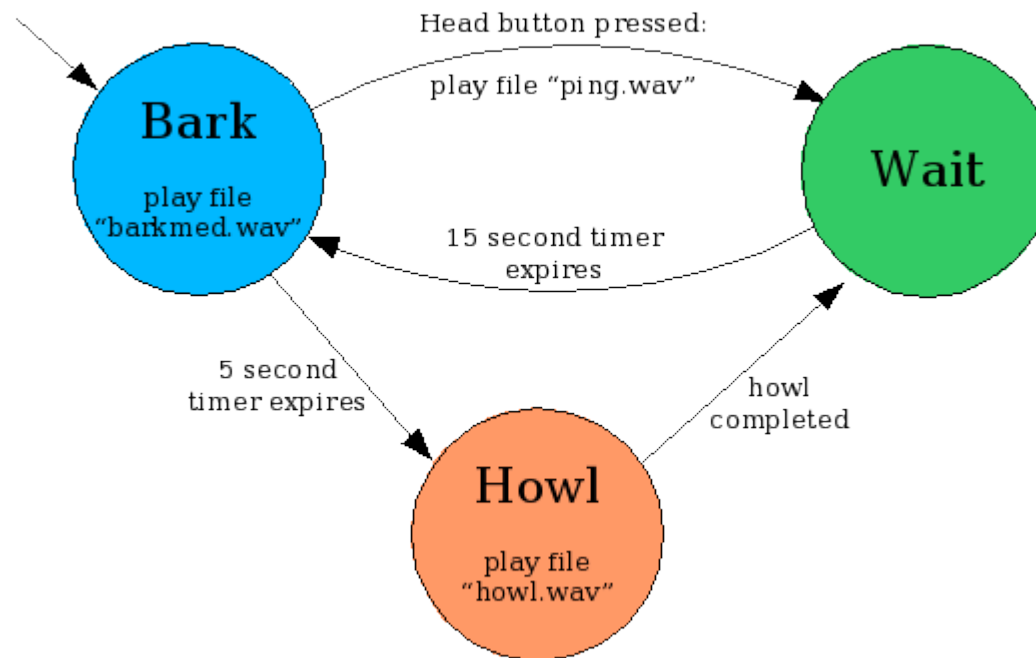
Types of State Nodes

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

BehaviorBase

StateNode

MCNode<T>

LedNode

HeadPointerNode

ArmNode

TailWagNode

PostureNode

WalkEngineNode

WalkToTargetNode

MotionSequenceNode

SoundNode

SpeechNode

LogNode

VisualRoutinesStateNode

All of these contain Motion Commands

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Types of Transitions


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Both State Nodes and Transitions Are Behaviors

- StateNode and Transition are both subclasses of BehaviorBase.

- Tekkotsu behaviors can contain arbitrary C++ code and can generate and/or receive events.

- Transitions:

  - A transition's start() method 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*.

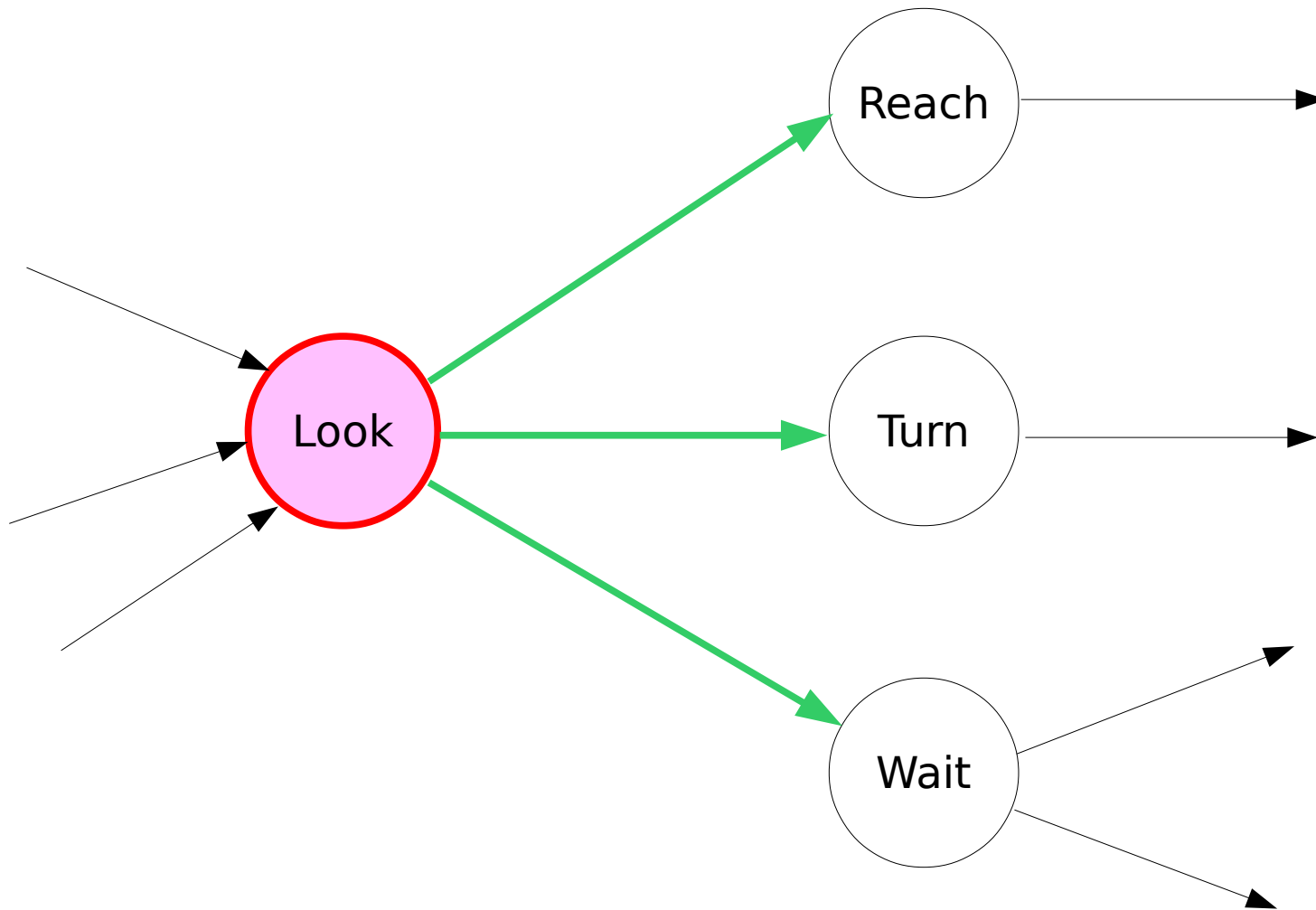 - When a transition fires, it deactivates its source node(s) and then activates its target node(s).

Transition firing activates state node Look.
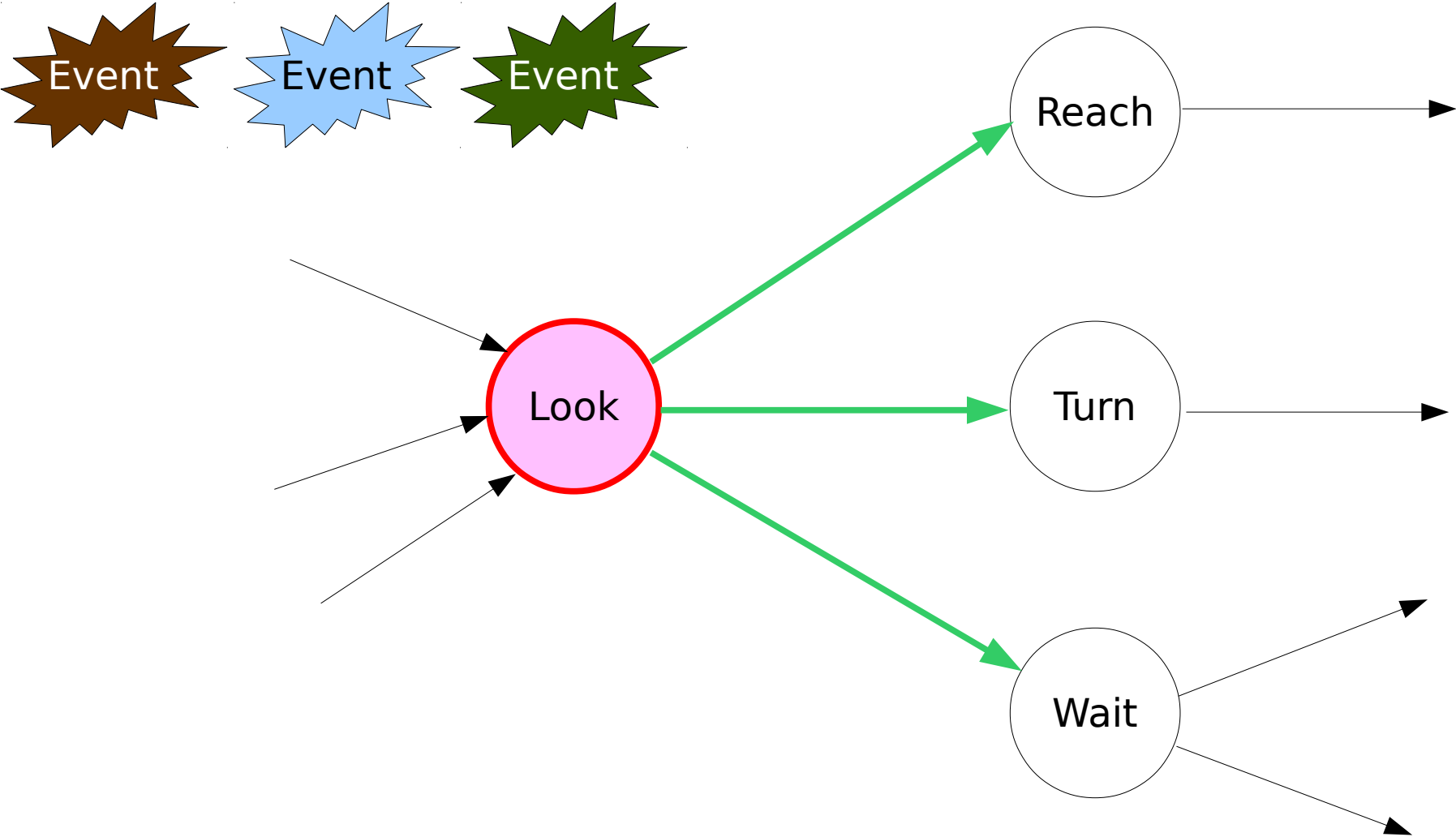
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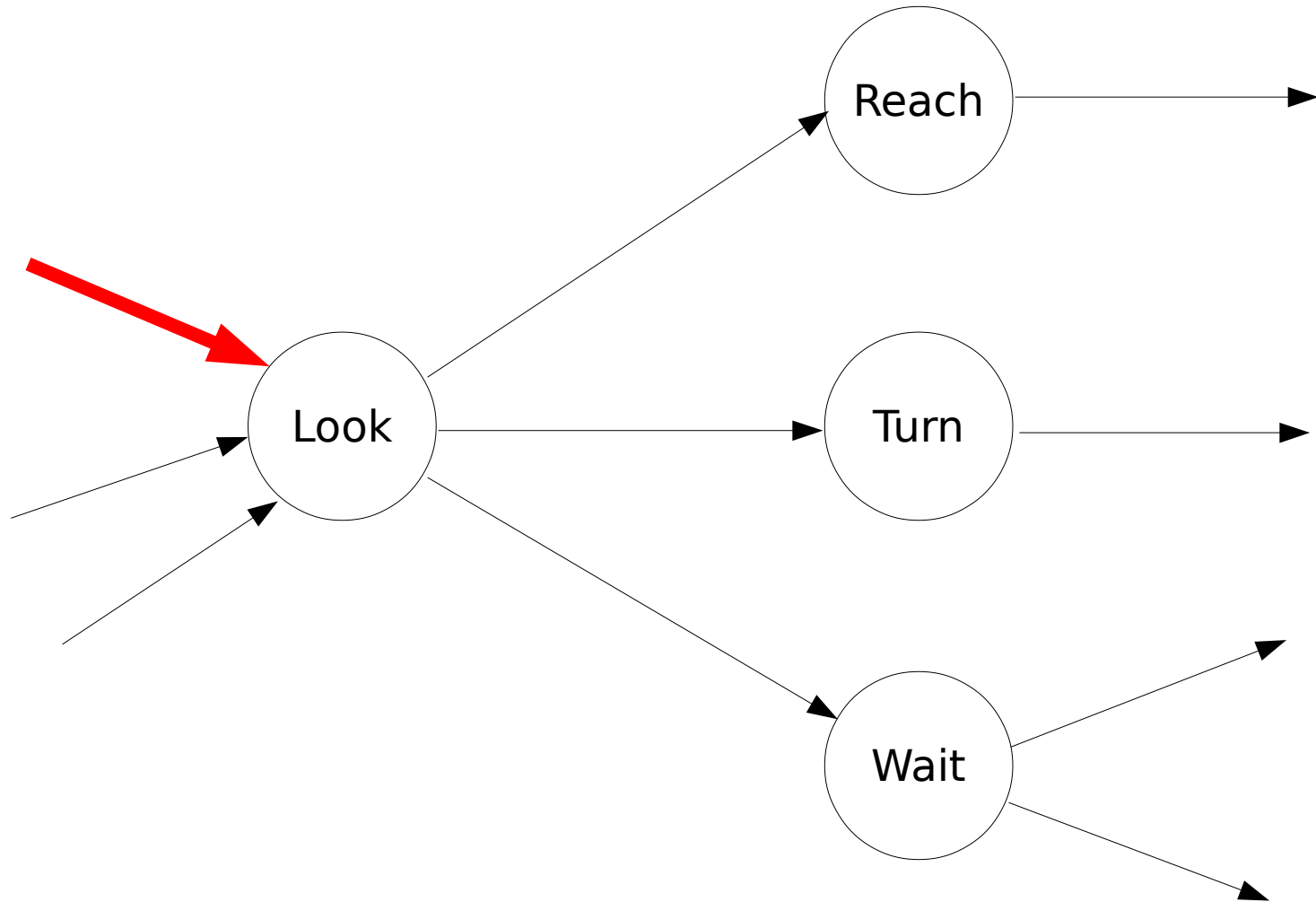
Look's start() calls StateNode::start().
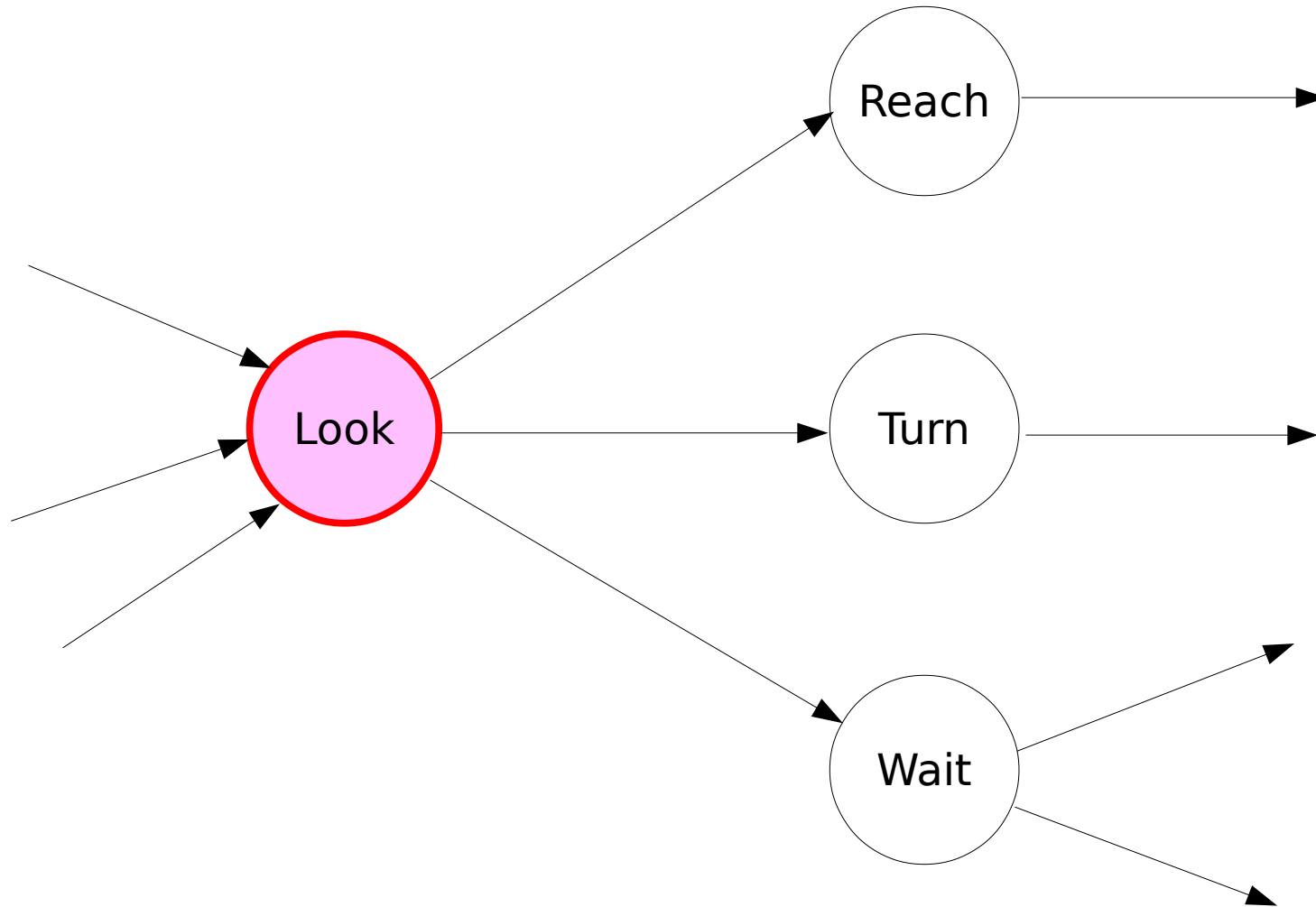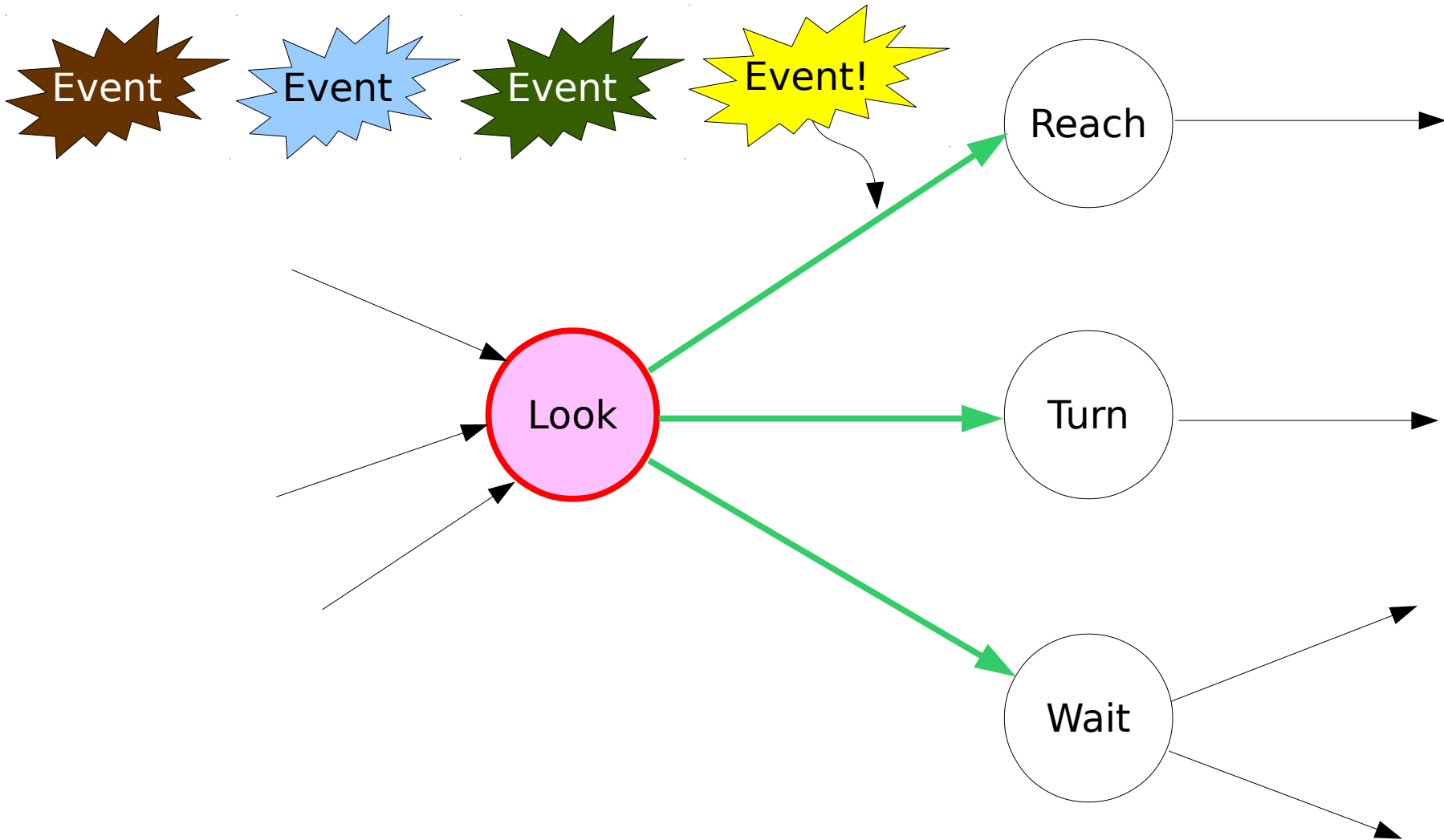
Outgoing transitions become active and
begin listening for events.

Random things happen....

Event Event Event

Look

Reach

Turn
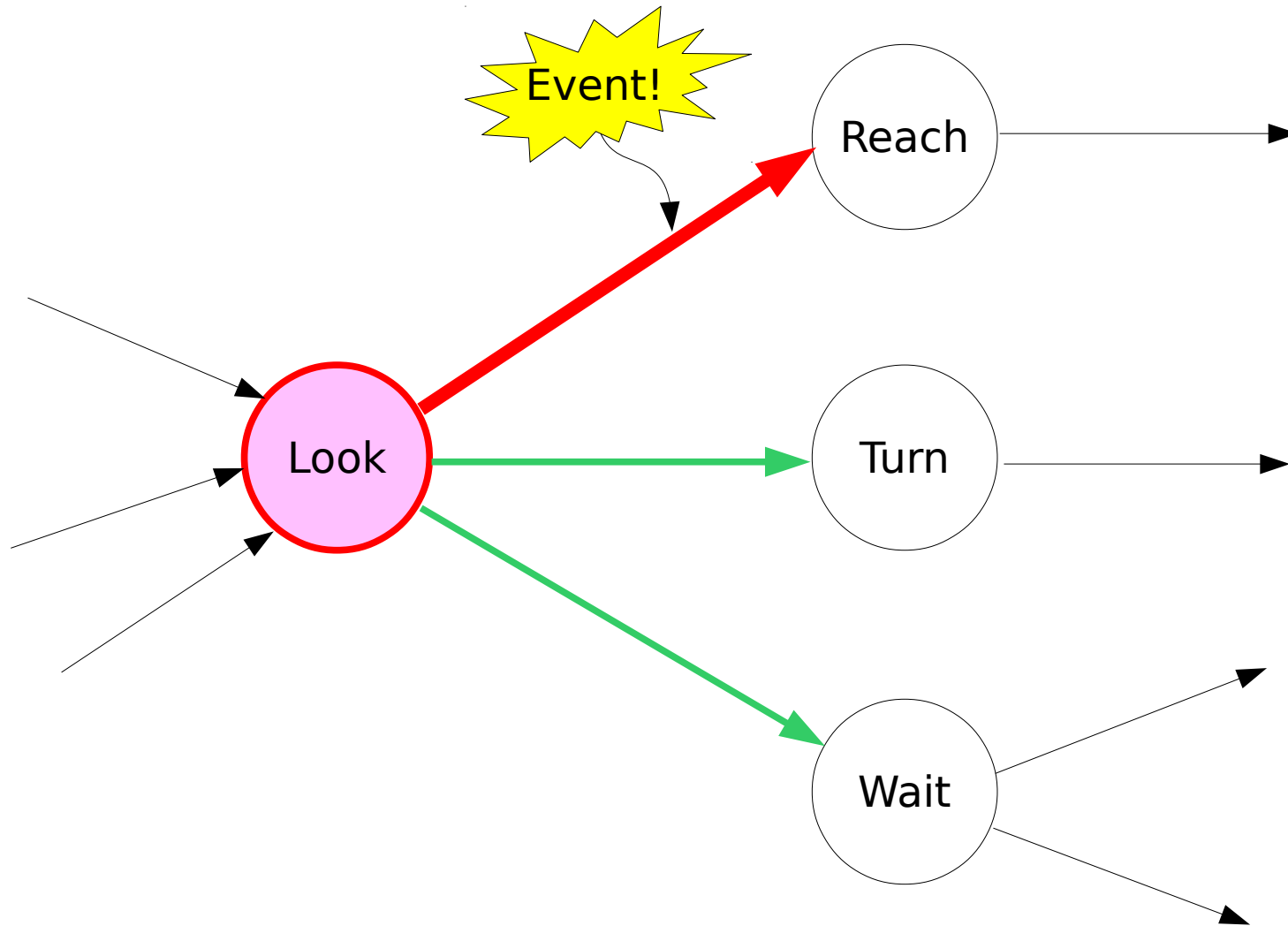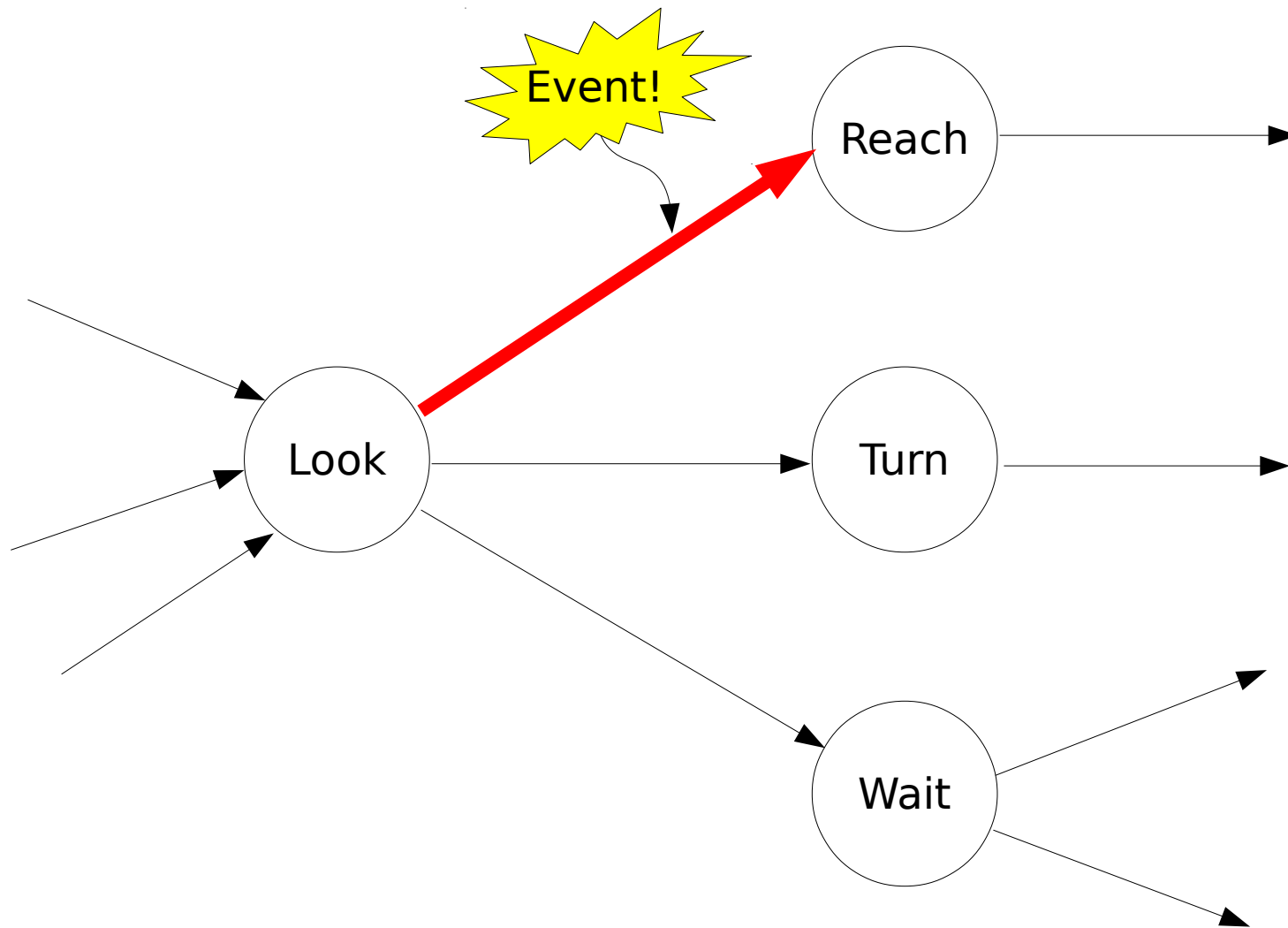
Wait

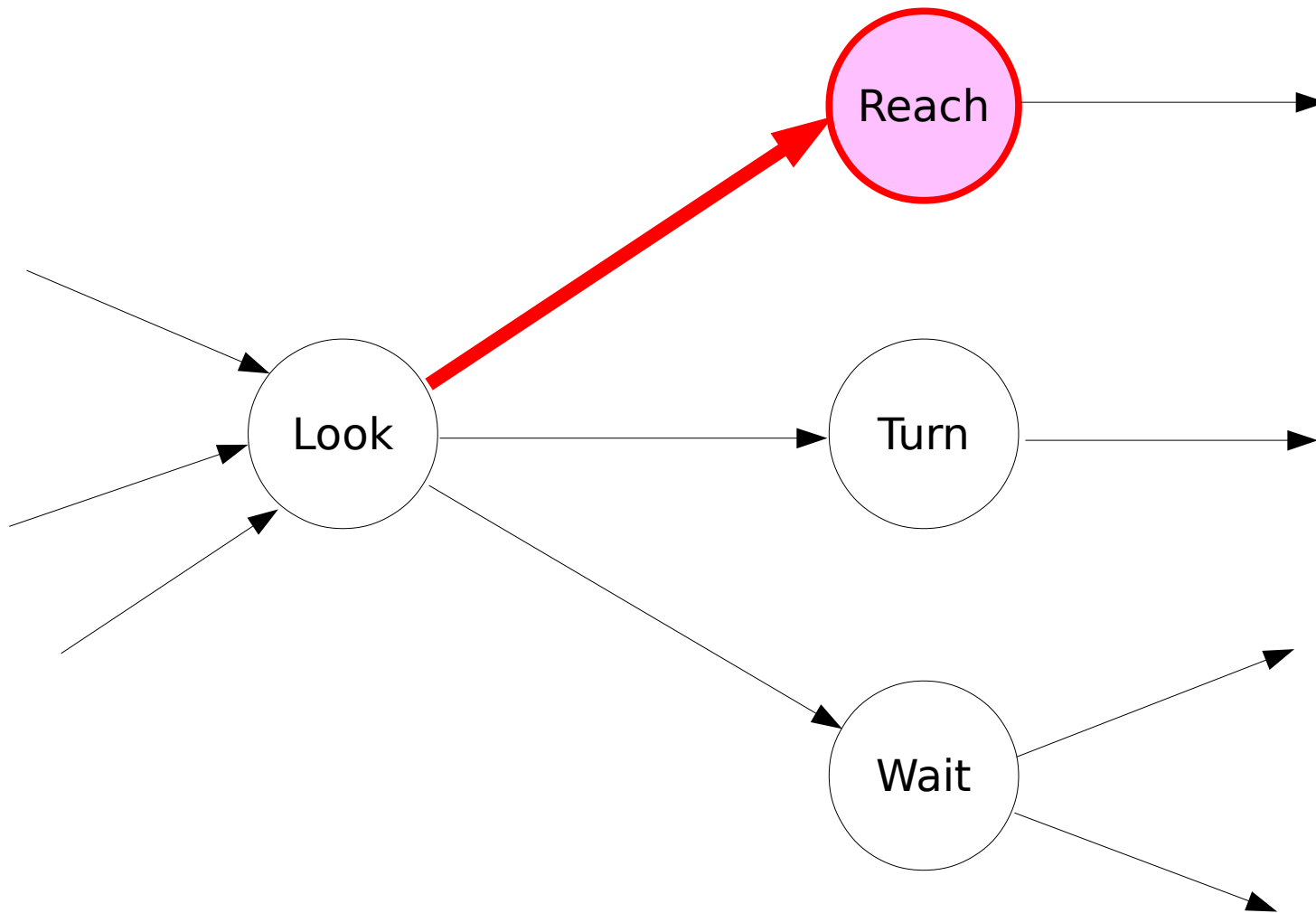And then, something we've been looking for...
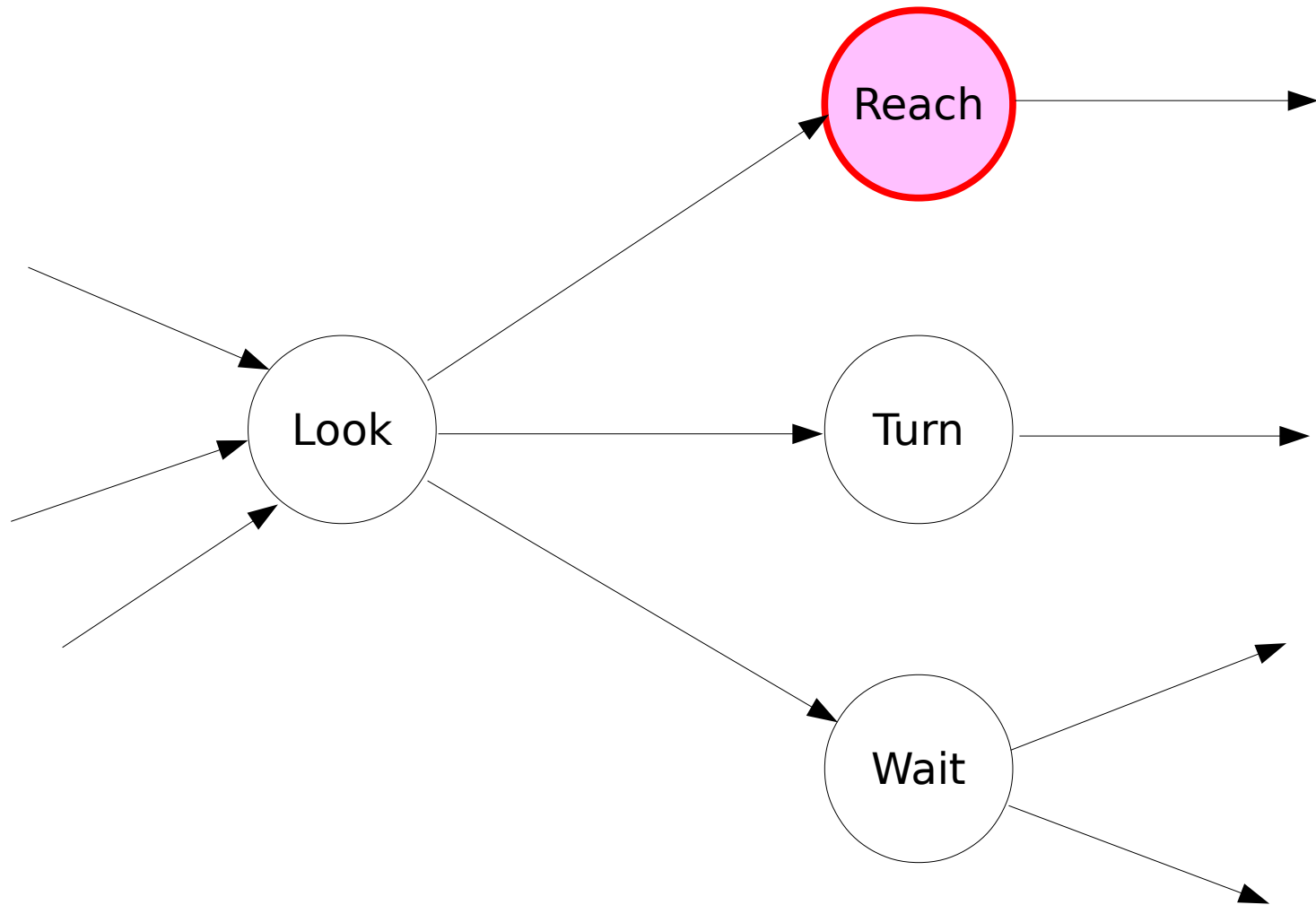
Transition decides to fire.

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Transition deactivates the source node, Look.

Transition activates the target node, Reach.

Transition deactivates.

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

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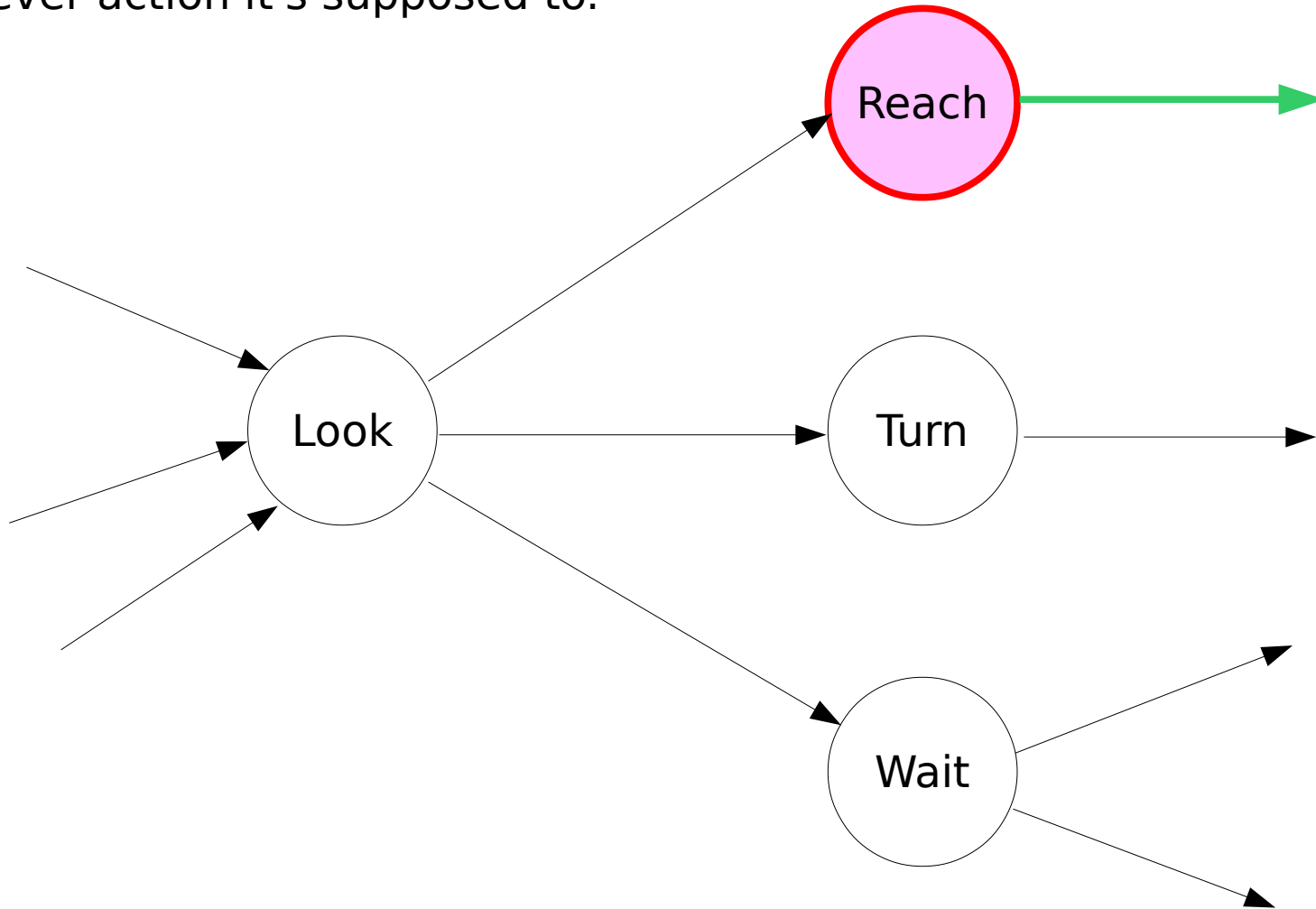
State Machine Compiler

- Tekkotsu programmers don't normally write C++ code to build state machines one node or link at a time.
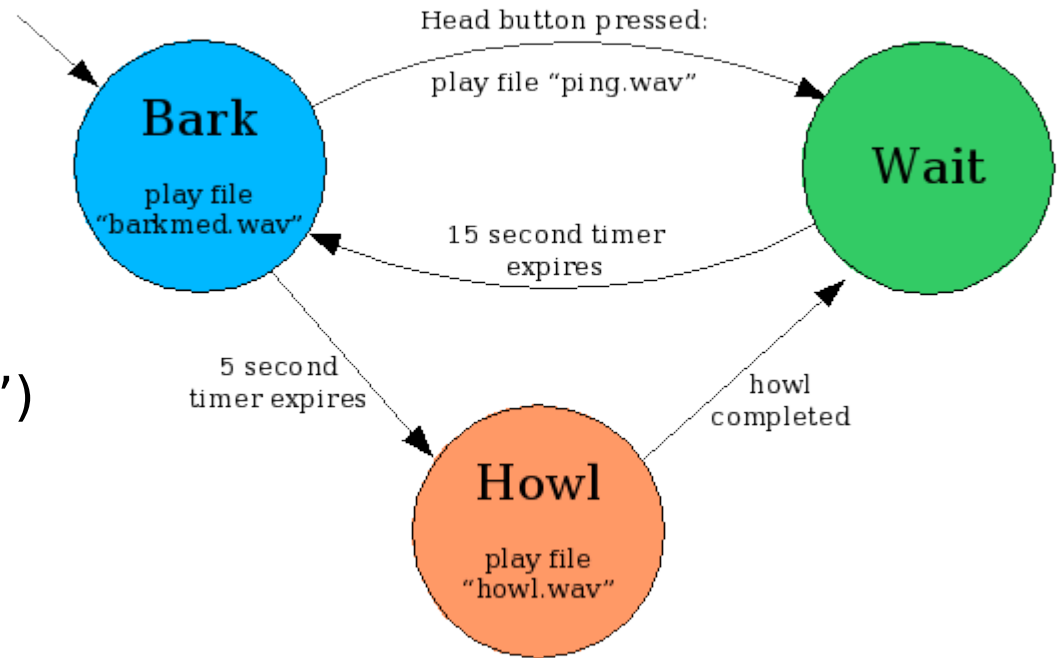
- Why not?

  - It's tedious.

  - It's error-prone.

- Instead they use a shorthand notation.

- The shorthand is turned into C++ by a state machine compiler.

Shorthand Notation

bark: SoundNode("barkmed.wav")

howl: SoundNode("howl.wav")

wait: StateNode

bark =T(5000)=> howl

bark =B(RobotInfo::PlayButOffset)[setSound("ping.wav")]=> wait

howl =C=> wait

wait =T(15000)=> bark

Real Code: AnnoyingDog.cc.fsm

#include "Behaviors/StateMachine.h"

$nodeclass AnnoyingDog **{**

  $setupmachine{

    bark: SoundNode("barkmed.wav")
    bark =T(5000)=> howl
    bark =B(RobotInfo::PlayButOffset)[setSound("ping.wav")]=> wait

    howl: SoundNode("howl.wav")
    howl =C=> wait

    wait: StateNode
    wait =T(15000)=> bark

  }

}

REGISTER_BEHAVIOR(AnnoyingDog);

Advanced Shorthand: Chaining

- "Kiddie code":

  say_hi: SpeechNode("Hi")
  say_bye: SpeechNode("Bye")
  say_why: SpeechNode("Why")

  say_hi =T(3000)=> say_bye

  say_bye =T(3000)=> say_why

- Chained code:

  SpeechNode("hi") =T(3000)=>
    SpeechNode("bye") =T(3000)=>
      SpeechNode("why")

Good Coding Style

- If a node has multiple outgoing transitions, don't use chaining.

    – Define the node first, on a separate line, with a label.

    – Then write each of the transitions below it.

- It's good to chain if a node has only one transition.

- Example:

```
look: LookForToys
look  =S=>  SpeechNode("a toy!")  =C=>  trygrab
look  =F=>  askforhelp
```

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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

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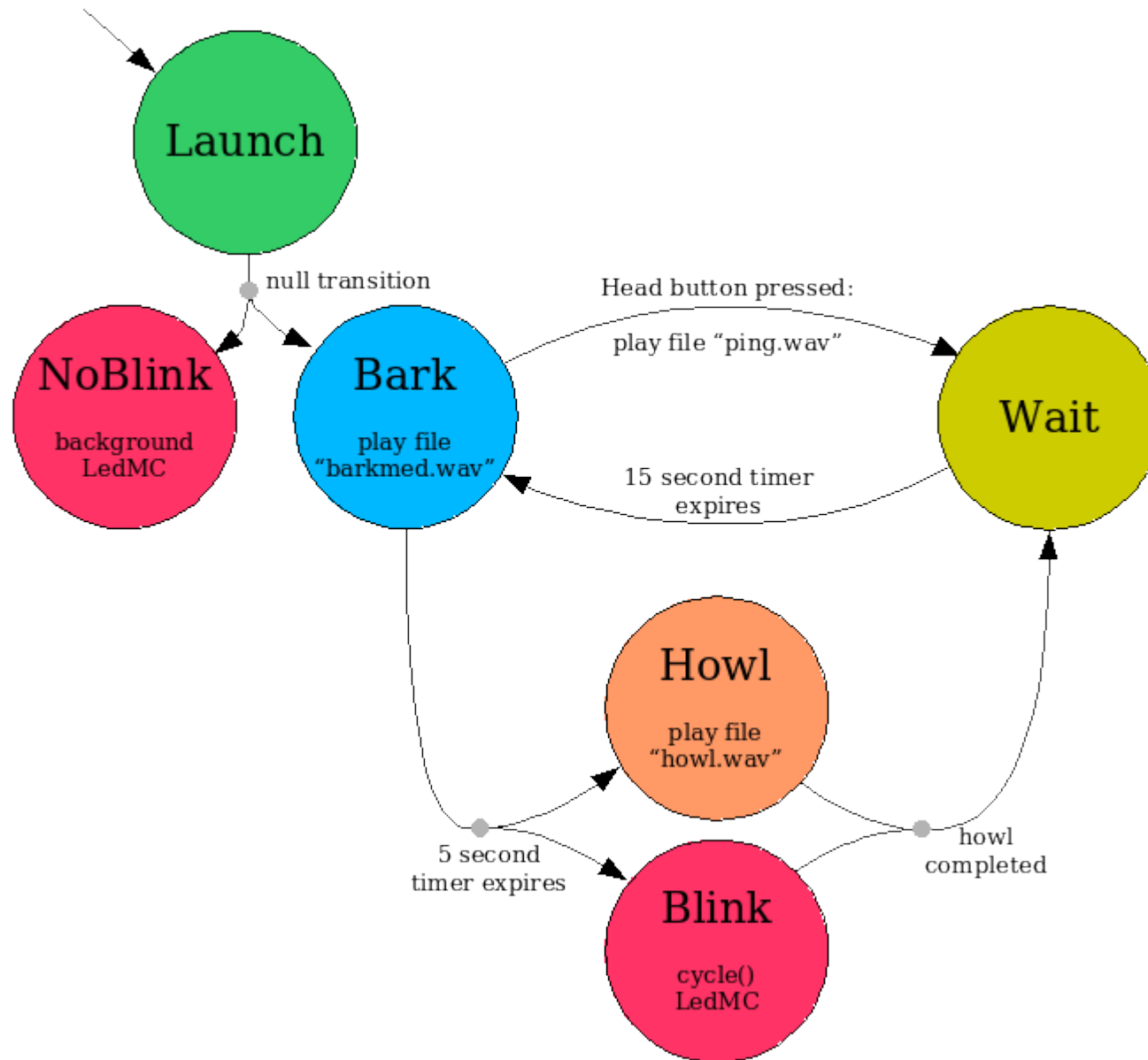
Blink Using LedEngine::cycle()

- 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.

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```
$setupmachine{
  // Annoying dog with blinking LEDs

  launch: StateNode =N=> {noblink, bark}

  noblink:      deferred


  bark: SoundNode("barkmed.wav")
  bark =B(PlayButOffset)[setSound("ping.wav")]=> wait
  bark =T(5000)=> {howl, blink}

  howl: SoundNode("howl.wav")

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

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

  wait: StateNode =T(15000)=> bark

}
```

What if we instead wrote this?
{howl, blink} =C=> wait

NoBlink in the Background

- When the robot isn't howling, we want all its LEDs to stay dark.

- But we can terminate the Blink node at any time; the LedNode might leave the LEDs in a partially-on state.

- Solution: have a second LEDNode called NoBlink programmed to keep the LEDs dark, but assign it a low priority.

- The Blink node will override NoBlink when it's active.

- When Blink is not active, NoBlink will keep the LEDs dark.

```
$setupmachine{
  // Annoying dog with blinking LEDs

  launch: StateNode =N=> {noblink, bark}

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

  bark: SoundNode("barkmed.wav")
  bark =B(PlayButOffset)[setSound("ping.wav")]=> wait
  bark =T(5000)=> {howl, blink}

  howl: SoundNode("howl.wav")

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

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

  wait: StateNode =T(15000)=> bark

}
```

Summary of Shorthand Notation

- Instantiating a node:

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

  Labels must begin with a lowercase letter.
  Class names must begin with an uppercase letter.

- 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:

  {src1, src2, ...}   =Transition=>   {targ1, targ2, ...}

Short and Long Forms

>==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)=>
success or failure transitions	=S=> or =F=>

Defining the Start Node

- If there is a node labeled **startnode,** it will be taken as the start node of the state machine.

- If there is no startnode, then the first node instance *defined* in the file is taken as the start node.

- Example:

  ```
  apple =C=> pear =C=> apple
  pear: SpeechNode("pear")
  apple: SpeechNode("apple")
  ```

  The start node will be pear, since it is the first node instance defined.

Defining New Node Classes

```
#include "Behaviors/StateMachine.h"

$nodeclass MyMachine {

  $nodeclass Greet : StateNode : doStart {
    cout << "Hello there!" << endl;
  }

  $nodeclass Sendoff : SpeechNode : doStart {
    textstream << "So long!" << endl;
  }

  $setupmachine{
      startnode: Greet =T(5000)=> Sendoff
  }

}

REGISTER_BEHAVIOR(MyMachine);
```

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:

  stateparser BarkHowlBlinkBehavior.cc.fsm –

Storyboard Tool: State Machine Layout
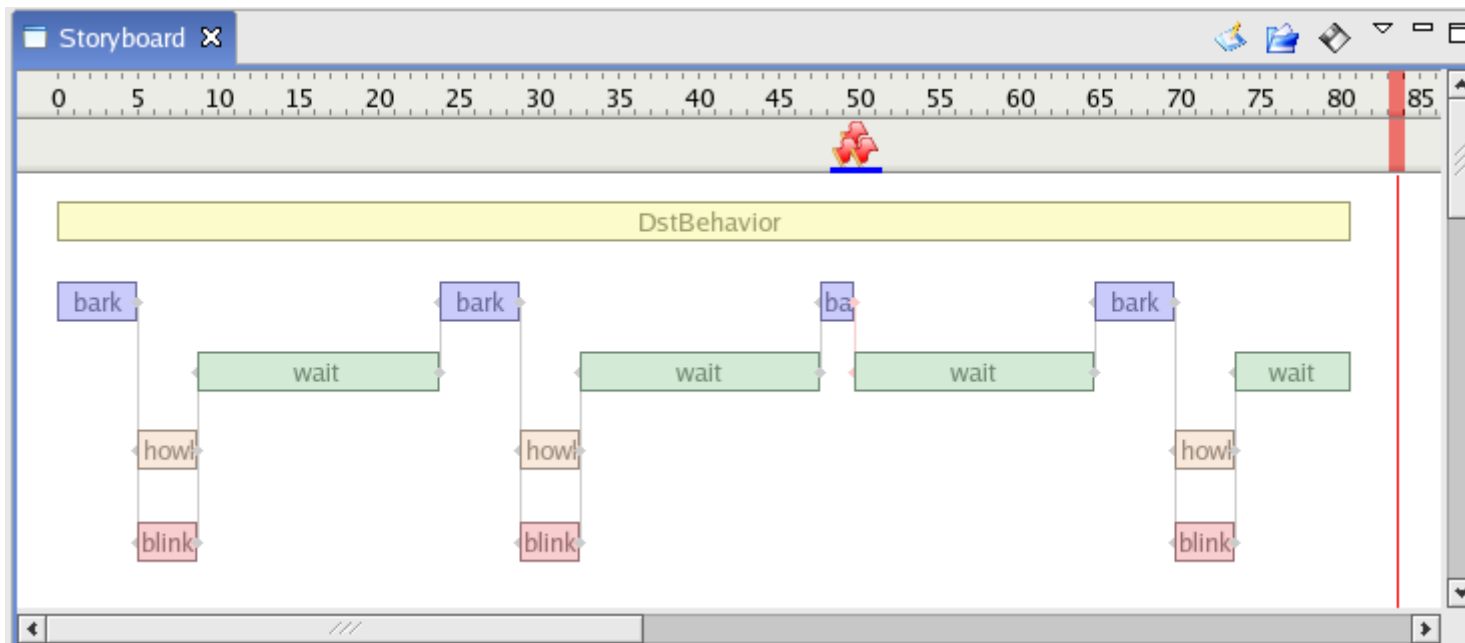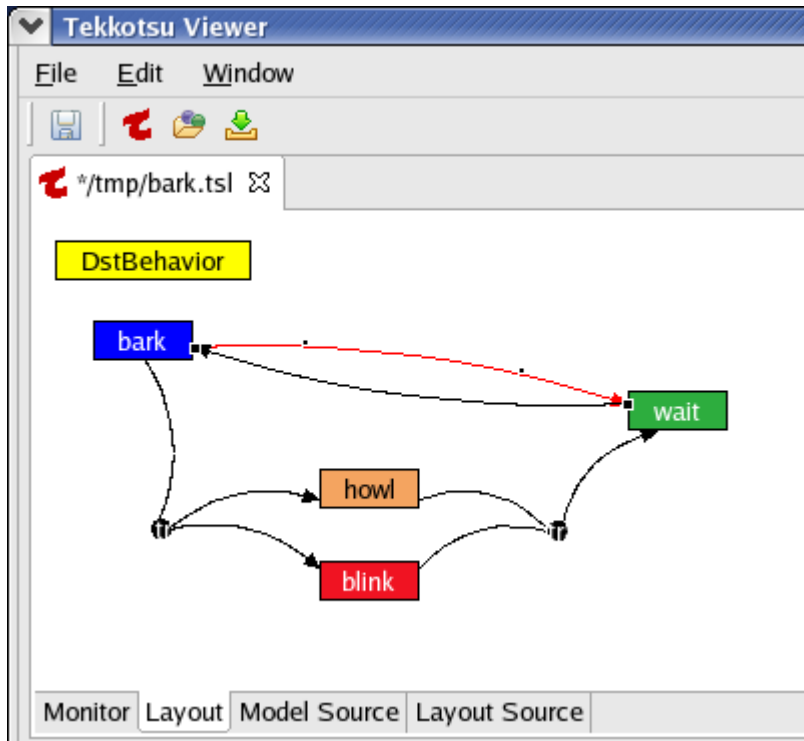
Storyboard Tool: Storyboard Display

Storyboard Tool: Snapshots