Nuts and Bolts: Modular AI from the Ground Up

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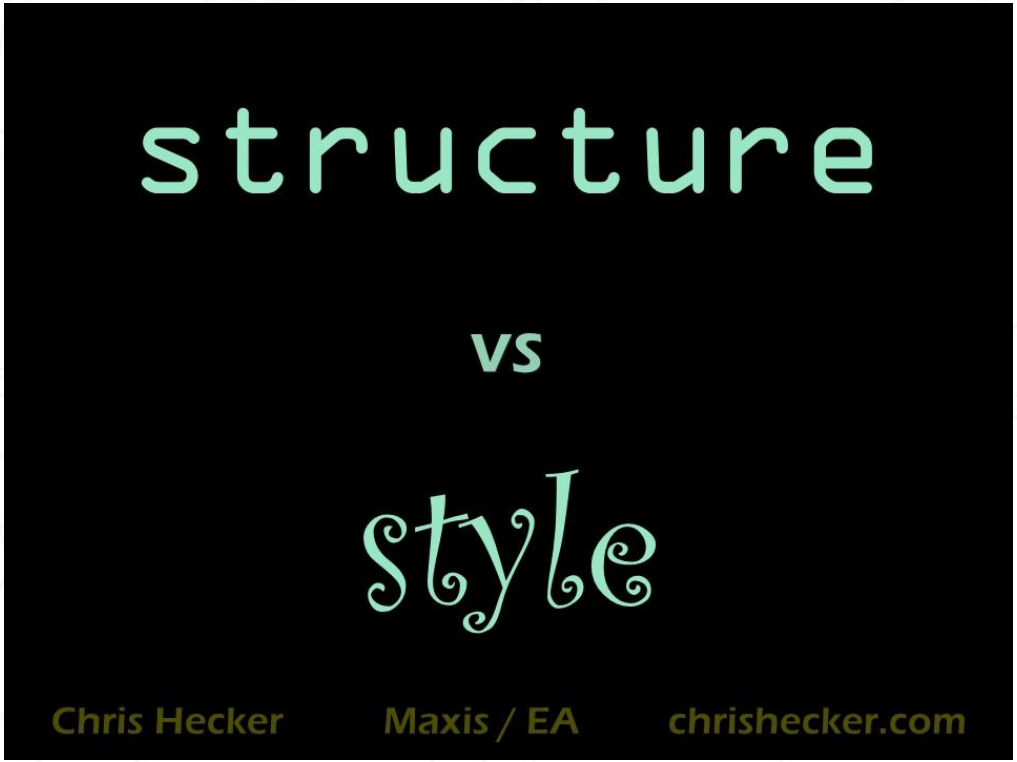
GDC
GAME DEVELOPERS CONFERENCE March 14–18, 2016 · Expo: March 16–18, 2016 #GDC16
UBM

Motivation

Chris Hecker
GDC 2008
http://chrishecker.com/Structure_vs_Style



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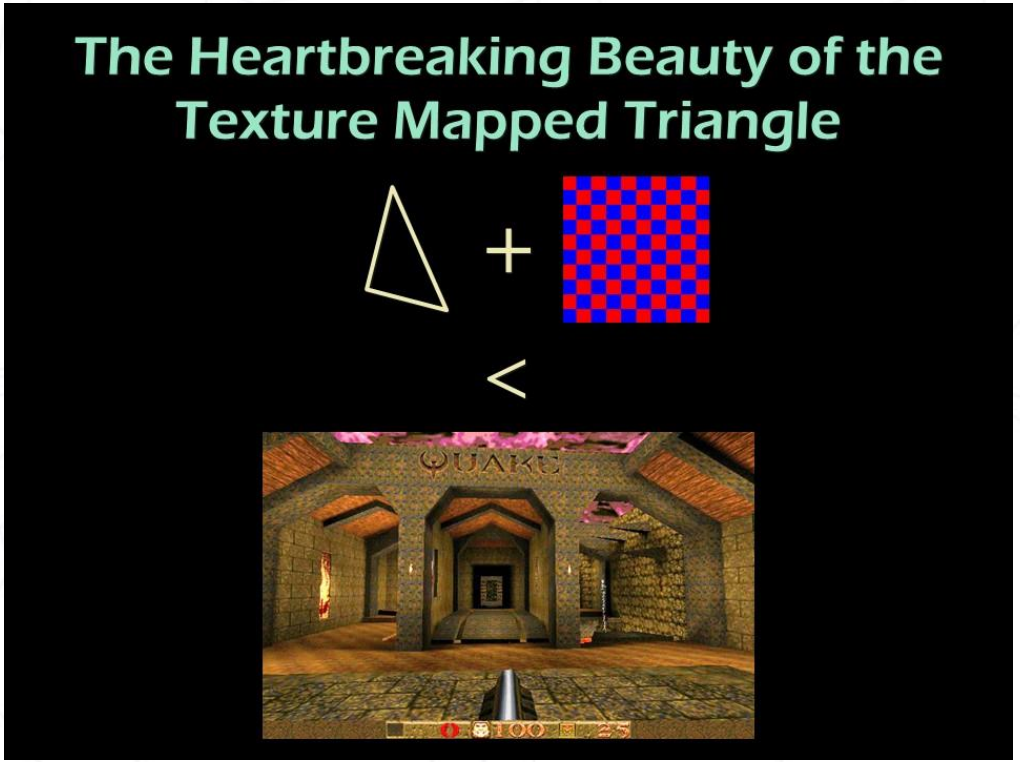

The Game AI Architecture (GAIA)

- Lockheed Martin's modular architecture
- Used across 6 very different projects
  - character AI / sniper AI / strategic simulation / flight simulator
- Integrated into multiple engines
  - Gamebryo / Real World
  - VBS2
  - Havok
  - Unity
  - JSAF (Joint Semi-Automated Forces) simulator
  - (in progress) TES (Tactical Environment Simulaton) simulator
  - (in progress) Web Server-based integration

Agenda

- What is Modular AI?
- Common Conceptual Abstractions
- Sniper Example
- Implementation
- Parting Thoughts

The Big Idea

- Level of granularity
  - "Bite-sized pieces"
  - Single human concept
- For example:
  - How far away is he?
  - How long have I been doing this?
  - Do I have any grenades?
  - I want to move over there
  - I want to shoot at that guy

Bite-Sized Pieces

- Conceptual Abstractions
  - Consideration
  - Action
- Modular Components
  - Distance Consideration
  - Move Action
- Implementation vs. Configuration

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Reasoners

- The thing that makes decisions
  - Utility-Based
  - Rule-Based
  - Sequence
  - …

```
class AIReasonerBase : public AIBase
{
public:
    virtual bool Init(const AICreationData& creationData);

    // Run any reasoner-specific sensors.
    void Sense(AIContext* pContext);

    // Think() is the meat of the reasoner.  It is typically called every
    //  frame. It handles selecting an option for execution, deselecting
    //  the previous option when the selected option changes, and then
    //  updating the selected option so that its actions can execute
    virtual void Think(AIContext* pContext);
};
```

Considerations

- Evaluate a single aspect of the current situation
  - Distance
  - Execution History
  - Picker
  - …

```
class AIConsiderationBase
{
public:
  virtual void Init(AICreationData& creationData) = 0;

  // Evaluate the situation and determine how “good” this option is.
  //  Store the results in m_Weights.  Access them with GetResults().
  virtual void Calculate() = 0;
  const AIWeightValues& GetResults() { return m_Weights; }

  // Some functions need to know when the associated option is
  //  selected/deselected (for example, to store timing information).
  virtual void Select(AIContext* /*pContext*/) {}
  virtual void Deselect(AIContext* /*pContext*/) {}

protected:
  AIWeightValues m_Weights;
};
```

Actions

- What to do when a particular option is selected
  - Move
  - Fire Weapon
  - Subreasoner
  - …

```
class AIActionBase
{
public:
  virtual void Init(AICreationData& creationData) = 0;

  // Called when the action starts/stops execution.
  virtual void Select() {}
  virtual void Deselect() {}

  // Called every frame while we're selected.
  virtual void Update() {}

  // Check whether this action is finished executing.  Some actions (such
  //  as a looping animation) are always considered to be done, but others
  //  (such as moving to a position) can be completed.
  virtual bool IsDone() { return true; }
};
```

Targets

- Represents a position and (optionally) an entity
  - Fixed Position
  - Named Entity
  - Controlled Entity
  - …

```
class AITargetBase
{
public:
  virtual bool Init(const AICreationData& cd);

  // Get the target's position
  virtual const AIVectorBase& GetPosition() const = 0;

  // Get the entity associated with this target (if any)
  virtual AIEntity* GetEntity() const { return NULL; }
  virtual bool HasEntity() const { return false; }
};
```

Weight Functions

- Convert from an input (e.g. Float, Boolean, etc.) to weight values
  - Boolean
  - Float Sequence
  - Simple Curve
  - …

```
class AIWeightFunctionBase
{
public:
  virtual bool Init(const AICreationData& cd) = 0;

  // Weight functions can deliver a result based on the input of
  //  a bool, int, or float.  By default bool and float both throw
  //  an assert, and int calls float.
  virtual const AIWeightValues& CalculateBool(bool b);
  virtual const AIWeightValues& CalculateInt(int i);
  virtual const AIWeightValues& CalculateFloat(float f);

  // Some functions need to know when the associated option is
  //  selected/deselected (for example, to readjust random values).
  virtual void Select() {}
  virtual void Deselect() {}
};
```

Regions

- Represents a region of space with an inside and an outside
  - Circle
  - Rectangle
  - Polygon
  - …

```
class AIRegionBase
{
public:
  virtual bool Init(const AICreationData& cd);

  // Test if the passed in location is within the geometry.
  virtual bool InRegion(const AIVectorBase& position) const = 0;

  // Get a random position within the geometry
  // NOTE: IT IS POSSIBLE FOR THIS TO FAIL!! It returns success.
  virtual bool GetRandomPosition2d(AIVectorBase& outVal) const =
0;
};
```

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Sniper

- Periodically (every minute or two) takes a shot at the enemy
  - Not if there is no line of retreat
  - Decrease priority with each additional shot

Sniper - The "Take A Shot" Option

Take A Shot

Considerations

- Execution History (Timer)
- Picker (Select Target)
- Picker (Line of Retreat)
- Integer Variable (Number of Shots)

Actions

- Write Blackboard (# Shots Fired)
- Fire at Target

```
<Option Type="ConsiderationAndAction" Comment="Take A Shot">
  <Considerations>
    <Consideration Type="ExecutionHistory">
      <StoppedWeightFunction Type="FloatSequence">
        <Entries>
          <Entry Min="60" Max="120" Veto="true"/>
        </Entries>
        <Default Veto="false"/>
      </StoppedWeightFunction>
    </Consideration>
    <Consideration Type="Global" Name="PickTarget"/>
    <Consideration Type="Global" Name="CheckRetreat"/>
    <Consideration Type="IntegerVariable" Variable="NumShots">
      <WeightFunction Type="BasicCurve"> ... </WeightFunction>
    </Consideration>
  </Considerations>
  <Actions>
    <Action Type="UpdateIntegerVariable" Variable="NumShots"
            UpdateType="Increment"/>
    <Action Type="Global" Name="FireAtTarget">
  </Actions>
</Option>
```

What Does This Buy Me?

```
<Consideration Type="ExecutionHistory">
  <StoppedWeightFunction Type="FloatSequence">
    <Entries>
      <Entry Min="60" Max="120" Veto="true"/>
    </Entries>
    <Default Veto="false"/>
  </StoppedWeightFunction>
</Consideration>
```

- Appropriate level of abstraction
  - Enter ~6 values vs. a couple hundred lines of code
  - Those values are the relevant ones
- Broad reuse of both components (code) and behavior (XML)
  - Implement once
  - Fewer bugs
  - More mature code (better tested, more feature-rich)
- The Bottom Line: Developer Flow

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Polymorphism

- Defines the interface
- Decouples interface from implementation

```
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public:
  virtual void Init(AICreationData& creationData) = 0;

  // Evaluate the situation and determine how “good” this option is.
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  virtual void Calculate() = 0;
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  // Some functions need to know when the associated option is
  //  selected/deselected (for example, to store timing information).
  virtual void Select(AIContext* /*pContext*/) {}
  virtual void Deselect(AIContext* /*pContext*/) {}

protected:
  AIWeightValues m_Weights;
};
```

Factories

- Input: AICreationData
  - An XML node
  - Context data (the blackboard, the parent entity, the parent option, etc.)
- Output: an object of the appropriate subtype
- E.G. AIConsiderationFactory

```
template<class T>
class AIFactoryBase
{
public:
  T* Create(AICreationData& creationData);

  // Add a custom constructor.  Takes ownership of the constructor.
  void AddConstructor(AIConstructorBase<T>* pConstructor);
};
```

Factories - Bells & Whistles

- Constructors
  - Constructor objects can be added to the factory
  - Each constructor knows how to instantiate some types

- Why?
  - Allow external libraries to inject custom types without dependencies

```
template<class T>
class AIFactoryBase
{
public:
  T* Create(AICreationData& creationData);

  // Add a custom constructor.  Takes ownership of the constructor.
  void AddConstructor(AIConstructorBase<T>* pConstructor);
};
```

Factories - Bells & Whistles

- Templates & Macros
  - Consistent naming => automated factory specification
- Why:
  - Every factory works exactly the same way
  - Adding a new *type* of object is dead simple

Macro Magic: Declaring Factories

```
#define DECLARE_GAIA_FACTORY(_TypeName)                                                \
    class AI##_TypeName##Base;                                                         \
                                                                                       \
    class AI##_TypeName##Constructor_Default : public AIConstructorBase<AI##_TypeName##Base> \
    {                                                                                  \
    public:                                                                            \
        virtual AI##_TypeName##Base* Create(const AICreationData& creationData);       \
    };                                                                                 \
                                                                                       \
    class AI##_TypeName##Factory : public AIFactoryBase<AI##_TypeName##Base>           \
    {                                                                                  \
    public:                                                                            \
        AI##_TypeName##Factory()                                                       \
            { AddConstructor(new AI##_TypeName##Constructor_Default); }                \
    };
#undef DECLARE_GAIA_FACTORY
```

Combining Considerations

- AIGH! Not enough time!
  - Kevin Dill (2016): a simple Boolean approach
    - "Quick and Dirty: 2 Lightweight AI Architectures"
  - Mike Lewis & Dave Mark (2015): a utility-based approach
    - "Building a Better Centaur: AI at Massive Scale"
  - Kevin Dill & Dave Mark (2012): a dual-utility approach
    - "Embracing the Dark Art of Mathematical Modeling in AI"
- I strongly recommend the third - it's:
  - Straightforward to implement
  - Extremely flexible - capable of great power (hardcore utility-based AI) or great simplicity (each consideration is a "yes" or "no")
  - Avoids combinatoric problems of Mike & Dave's approach
- You can customize this in the Consideration Set!

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What Does This Buy Me?

```
<Consideration Type="ExecutionHistory">
  <StoppedWeightFunction Type="FloatSequence">
    <Entries>
      <Entry Min="60" Max="90" Veto="true"/>
    </Entries>
    <Default Veto="false"/>
  </StoppedWeightFunction>
</Consideration>
```

- Appropriate level of abstraction
  - Enter 6 values vs. several hundred lines of code
  - Those values are the relevant ones
- Broad reuse of both components (code) and behavior (XML)
  - Implement once
  - Fewer bugs
  - More mature code (better tested, more feature-rich)
- The Bottom Line: Developer Flow

Where To Start?

- You don't have to build a new architecture from scratch
  - If you do, it doesn't have to be as complex as mine
- Look for opportunities to build in a modular way
  - Weapon selection
  - Target selection
  - Red Dead example (missed opportunity)
- Start with considerations

The Mars Game

- Simple open-source implementation
  - Apache 2 license
  - GitHub: https://github.com/virtual-world-framework/mars-game
    - or Google “GitHub Mars Game”

AI ARTIFICIAL INTELLIGENCE SUMMIT

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Kevin Dill
Christopher Dragert
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Factories - Bells & Whistles

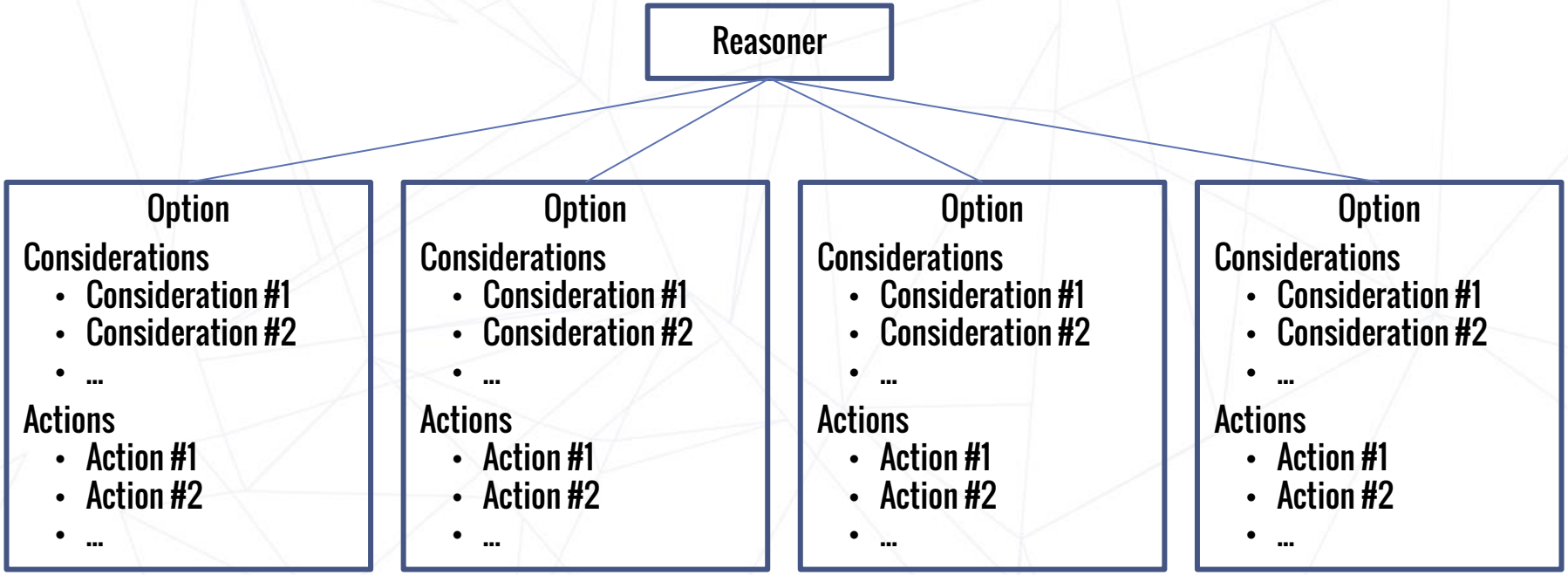
- Constructors
  - Constructor objects can be added to the factory
  - Each constructor knows how to instantiate some types

- Why?
  - Allow external libraries to inject custom types without dependencies

```
template<class T>
class AIFactoryBase
{
public:
  T* Create(AICreationData& creationData);

  // Add a custom constructor.  Takes ownership of the constructor.
  void AddConstructor(AIConstructorBase<T>* pConstructor);
};
```

Major Components



Sniper

- Periodically (every minute or two) takes a shot at the enemy.
  - Not if there is no line of retreat.
  - Not if under fire.
- Withdraws after firing a few shots
- Withdraws if the enemy opens fire
  - If he can't withdraw, returns fire instead

Sniper

Rule-Based Reasoner

- Periodically (every minute or two) takes a shot at the enemy.
  - Doesn't fire if there is no line of retreat.
  - Doesn't fire if under fire.
- Withdraws after firing a few shots
- Withdraws if the enemy opens fire
  - If he can't withdraw, returns fire instead

Withdraw

Considerations
- Blackboard (# Shots Fired)
- Event (Under Fire)
- Picker (Line of Retreat)
- Execution History (Commit)

Actions
- Withdraw

Fight

Considerations
- Event (Under Fire)
- Picker (Select Target)
- Execution History (Commit)

Actions
- Fire at Target

Take A Shot

Considerations
- Execution History (Timer)
- Picker (Select Target)
- Picker (Line of Retreat)

Actions
- Fire at Target
- Write Blackboard (# Shots Fired)

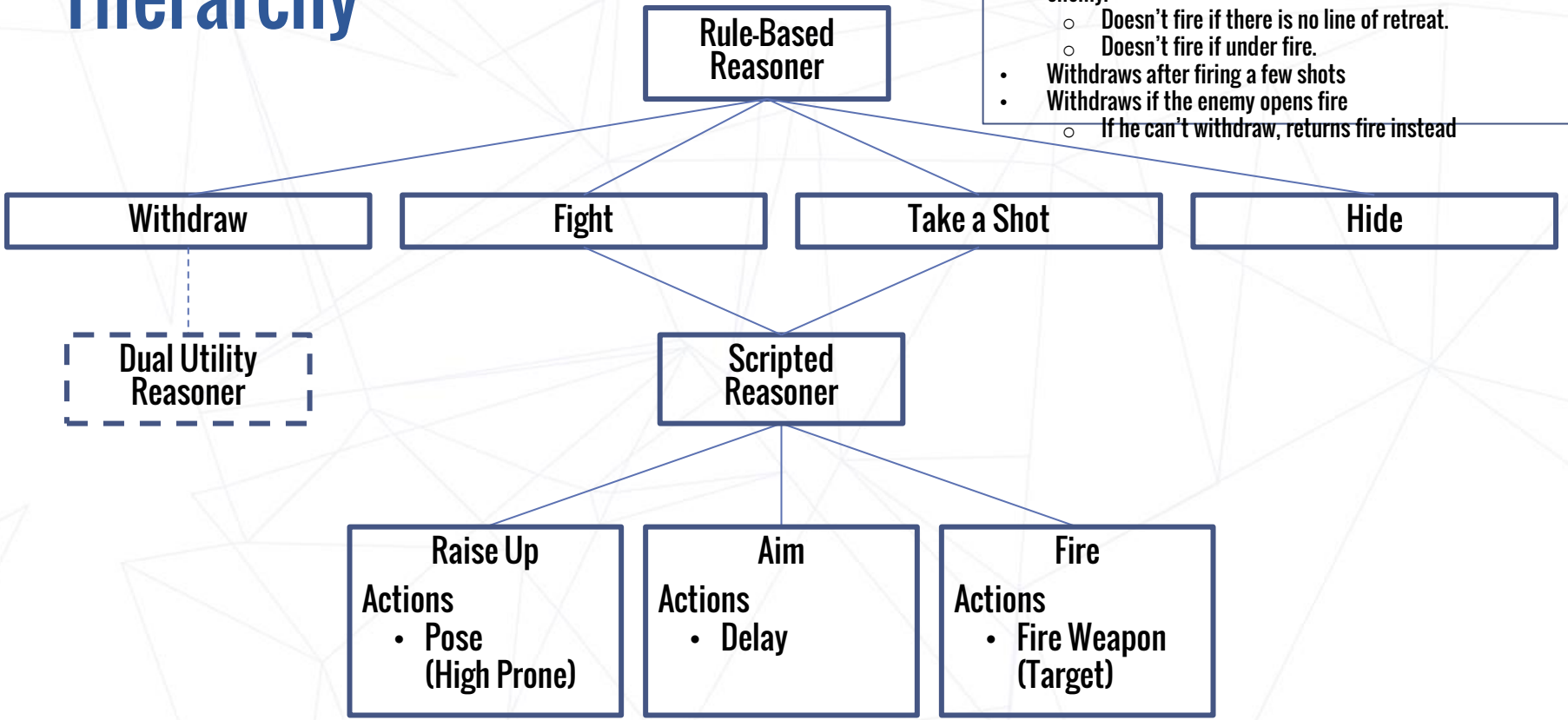
Hide

Considerations

Actions
- Pose (Low Prone)

Hierarchy

- Periodically (every minute or two) takes a shot at the enemy.
  - Doesn't fire if there is no line of retreat.
  - Doesn't fire if under fire.
- Withdraws after firing a few shots
- Withdraws if the enemy opens fire
  - If he can't withdraw, returns fire instead



Sniper - The “Hide” Option

Hide

Considerations

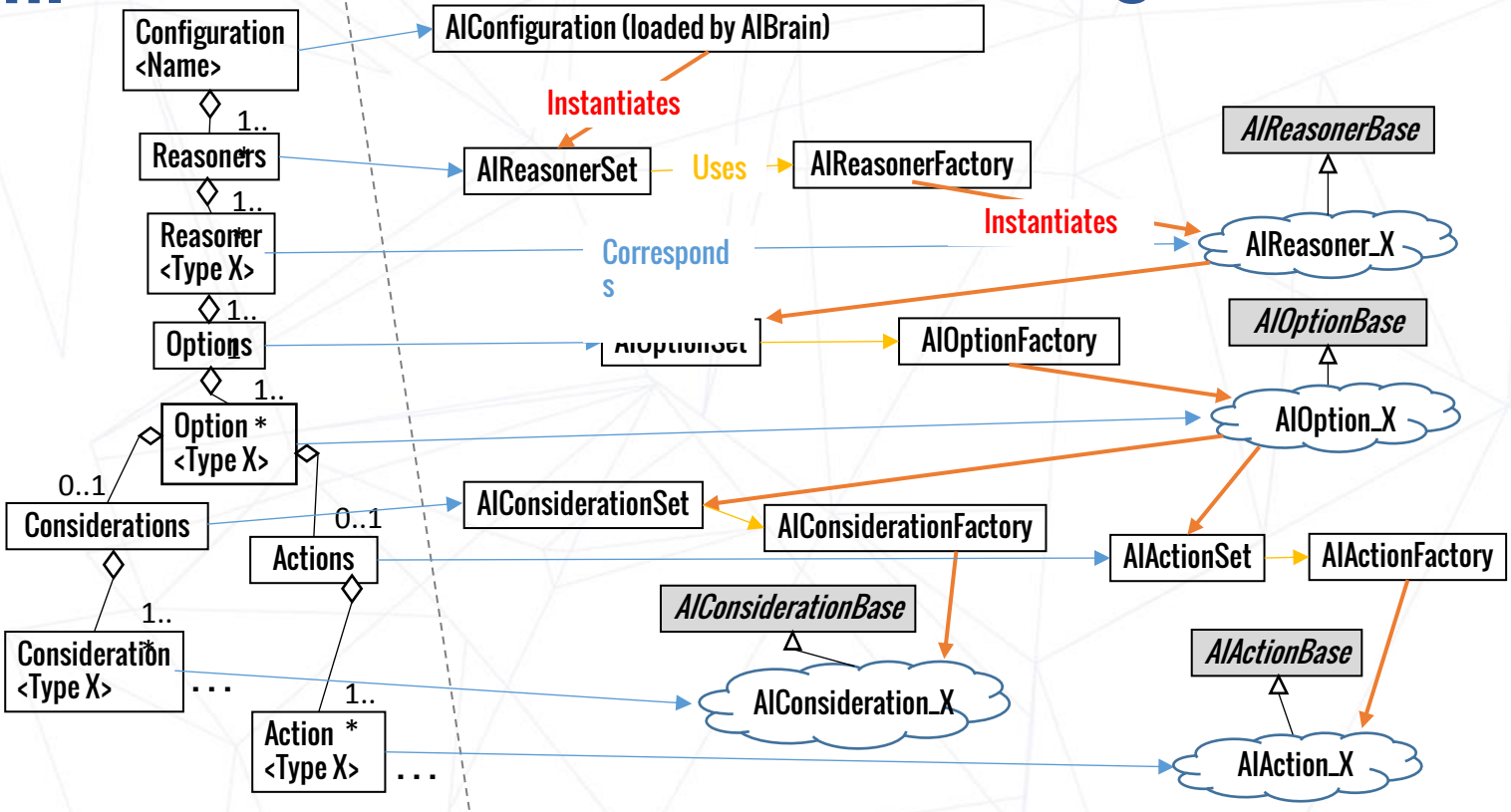
Actions

- Pose (Low Prone)

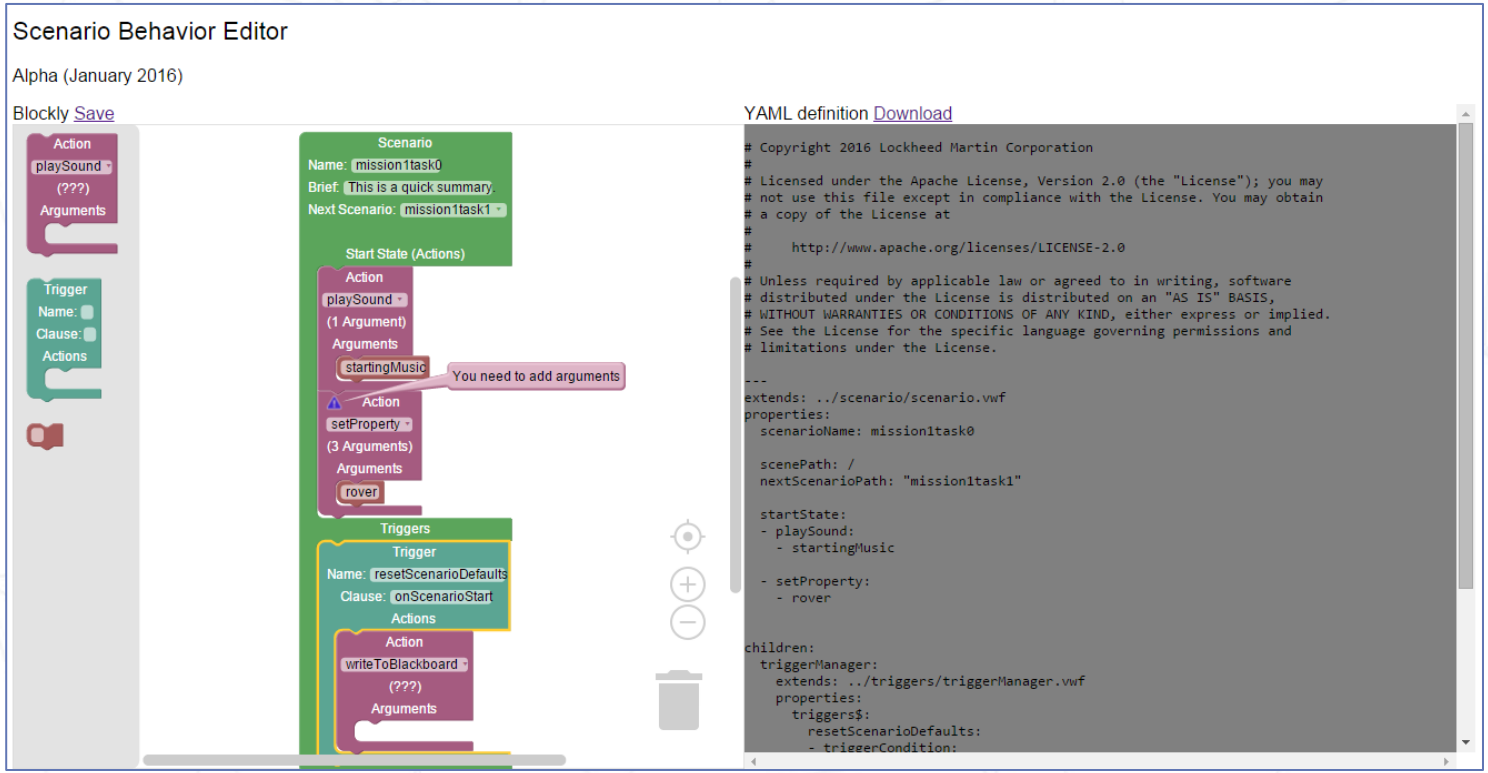
```
<Option Type="ConsiderationAndAction" Comment="Hide">
  <Considerations>
  </Considerations>
  <Actions>
    <Action Type="Pose" Pose="LowProne"
  </Actions>
</Option>
```

Xml

C++


Configuration <Name>
AIConfiguration (loaded by AIBrain)
Instantiates
1..
Reasoners
AIReasonerSet
Uses
AIReasonerFactory
AIReasonerBase
1..
Reasoner <Type X>
Instantiates
AIReasoner_X
Correspond s
1..
Options
AIOptionFactory
AIOptionBase
1..
Option * <Type X>
AIOption_X
0..1
Considerations
AIConsiderationSet
AIConsiderationFactory
0..1
Actions
AIActionSet
AIActionFactory
AIConsiderationBase
1..
Consideration <Type X>
AIConsideration_X
AIActionBase
1..
Action * <Type X>
AIAction_X

Tools


Scenario Behavior Editor
Alpha (January 2016)
Blockly Save
YAML definition Download
Action
playSound
(???)
Arguments
Trigger
Name:
Clause:
Actions
Scenario
Name: mission1task0
Brief: This is a quick summary.
Next Scenario: mission1task1
Start State (Actions)
Action
playSound
(1 Argument)
Arguments
startingMusic
You need to add arguments
Action
setProperty
(3 Arguments)
Arguments
rover
Triggers
Trigger
Name: resetScenarioDefaults
Clause: onScenarioStart
Actions
Action
writeToBlackboard
(???)
Arguments
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http://www.apache.org/licenses/LICENSE-2.0
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Unless required by applicable law or agreed to in writing, software
distributed under the License is distributed on an "AS IS" BASIS,
WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
See the License for the specific language governing permissions and
limitations under the License.
---
extends: ../scenario/scenario.vwf
properties:
scenarioName: mission1task0
scenePath: /
nextScenarioPath: "mission1task1"
startState:
- playSound:
- startingMusic
- setProperty:
- rover
children:
triggerManager:
extends: ../triggers/triggerManager.vwf
properties:
triggers$:
resetScenarioDefaults:
- triggerCondition: