General introduction

Virtual humans & behaviors

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Interest in using rich and complex virtual worlds inhabited by virtual beings with human-like behavior

- Military simulations and training
- Therapeutic applications
- Serious “games”
- Virtual reporters
- Computer games (having the best virtual world)
Show case 1

- Tactical Iraqi (by TacticalLanguage)
  - Training missions for U.S. Army soldiers
  - Very detailed
  - Gestures, Natural language recognition, Cultural customs
FEAR not!

- Therapeutic application
- Improvised dramas to address bullying problems for children aged 8-12
Outline

1. Virtual world / Virtual human “defs”
2. Virtual body
3. Virtual mind
   1. What it is?
   2. Typical problems
   3. Conceptual frameworks for implementations
   4. Combining reactive behavior and planning?
Virtual world
On the way to virtual human

We have a virtual world that resembles our own ...
... managed (simulated) by game engine
... inhabited by virtual humans which are trying to act as if they were human.
Virtual human

Definition

What is Virtual Human?
Virtual human

Definition

What is Virtual Human?

Subclass of Software Agent.
"An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors."

-- Russel & Norvig

"Autonomous agents are computational systems that inhabit some complex dynamic environment, sense and act autonomously in this environment, and by doing so realize a set of goals or tasks for which they are designed."

-- Maes

http://www.msci.memphis.edu/~franklin/AgentProg.html
Describing Software agent
Taxonomy

- Reactive / Sensing and acting
- Autonomous
- Goal-oriented / Pro-active
- Communicative / Socially able
- Learning / Adaptive
- Mobile
- Flexible
- Embodded
- Character / Believable
Virtual Human
Definition

- Reactive / Sensing and acting
- Autonomous
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Virtual Human
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Virtual Human
Can you tell?
Virtual Human
Can you tell?

- BotPrize prize-money-award competition
  [http://botprize.org/](http://botprize.org/)

- Target: create human-like opponent for Unreal Tournament 2004 videogame

- Let’s check it out...
  - Bot 489 vs. Bot 189, one of them is human... can you tell which one?
How to create virtual human for a given virtual environment that can perform given task in human-like fashion (in a real-time).
Virtual Human
Research question

How to create virtual human for a given virtual environment that can perform given task in human-like fashion (in a real-time).

“Cheating” is allowed!
Virtual Human
Components

- Virtual body
  - Graphical representation of the virtual human
  - Simulated by game engine
- Virtual mind
  - Responsible for actions
  - Simulated emotions, needs
  - May be simulated separately
Virtual Human

Components

Virtual Body
Virtual body
Excursion to computer graphics
Virtual body
More aspects

- Facial expressions, speech sync.
- Gestures (cultural customs?)
- Animation controller
  - Human-like motion planning (inverse kinematics)
  - Available animations limit actions of virtual humans
- Speech recognition, natural language processing, speech synthesis
- Emotion expression
Virtual Mind
Virtual Human
Components

Virtual Mind

1. What it is?
2. Typical problems
3. Conceptual frameworks for implementations
4. Combining reactive behavior and planning?
Virtual Human Components

Virtual Mind

1. What it is?
2. Typical problems
3. Conceptual frameworks for implementations
4. Combining reactive behavior and planning?
Virtual mind
What it is?

Virtual world (W)

Sensing (S) ➔ Virtual mind state (M) ➔ Acting (A)

Virtual body state (B)
Virtual mind
Suprisingly... a function

Virtual world (W) → Sensing (S) → Virtual mind state (M) → Acting (A) → Virtual body state (B)

\[ f(S,M,B) \rightarrow AxM \]
Virtual mind
Suprisingly... a function

Virtual world (W) → Sensing (S) → Acting (A) → Virtual mind state (M) → Virtual body state (B)

\[ f(W,\{Bi\},\{Ai\}) \rightarrow Wx\{Bi\} \]

\[ f(S,M,B) \rightarrow AxB \]
Virtual Human
Components

Virtual Mind

1. What it is?
2. Typical problems – components of virtual mind function
3. Conceptual frameworks for implementations
4. Combining reactive behavior and planning?
Virtual mind
Which tasks does it have?

- Satisfy virtual human goals
  - Express behavior - be reactive / pro-active / social
  - Perform action-selection (what to do next?)
- How to navigate
  - Path finding (planning)
- How to move
  - Path execution with obstacle avoidance
- What to remember
  - (Episodic) memory simulation (ask Cyril Brom)
- How to feel
  - Emotion simulations (ask Michal Bída 😊)
Virtual Mind

Components

Virtual Mind

1. What it is?
2. Typical problems – components of virtual mind function
   1. Navigation
   2. Action selection
3. Conceptual frameworks for implementations
4. Combining reactive behavior and planning?
Virtual mind
Navigation
Virtual mind

Navigation
Virtual mind
Navigation
Virtual mind
Navigation – Different approach
Virtual mind

Navigation – Points are needed nevertheless
Virtual mind
Navigation – Finding a path
Virtual mind
Navigation – Refining the path
Virtual mind

Navigation – Refining the path
Virtual mind
Path execution

- Obstacles?
  - Dynamically places objects
  - Other virtual humans
- Steering!
- Craig Raynolds applets
Virtual mind

Example of steering with ANN (GA, NEAT)
Virtual mind
Path navigation / execution solved?

- Still considered to be state of the art...
  - Automatic navigation graph construction
  - Quick path computations (imagine hundreds of units)
    - Hierarchical path-finding
  - Dynamic path-finding
  - Automatic detection of cover points
  - Movement of formations

- VIDEOS
Virtual Mind

Components

1. What it is?
2. Typical problems – components of virtual mind function
   1. Navigation
   2. Action selection implementation (Behavior decomposition)
3. Conceptual frameworks for implementations
4. Combining reactive behavior and planning?
Virtual mind
Action selection implementation

Virtual world (W)

Virtual body state (B)

Virtual mind state (M)

Sensing (S)

Acting (A)

\[ f(W,\{Bi\},\{Ai\}) \rightarrow Wx\{Bi\} \]

\[ f(S,M,B) \rightarrow AxE \]
Virtual mind
Action selection implementation

STATIC vs. DYNAMIC!

Virtual world (W)

Virtual body state (B)

Virtual mind state (M)

Sensing (S)

Acting (A)

\[ f(W,\{Bi\},\{Ai\}) \rightarrow Wx\{Bi\} \]

\[ f(S,M,B) \rightarrow AxM \]
Nothing new...

**TOTE** units: **T**est – **O**perate – **T**est – **E**xit

Miller, Galanter, Pribram: Plans and the Structure of Behavior (1960)
Virtual mind
Behavior decomposition

Test nail → (flush)
  (sticks up) → Test hammer → (up) → Strike
  (down) → Lift → (down) → Test hammer → (up)

Cyril Brom’s slides
Virtual mind
Behavior hierarchy

1. if bla1 and bla2 then SubGoal1
2. if not bla1 and bla3 then SubGoal2
3. if bla4 then SubGoal3

3.1 if A then Sub\textsuperscript{2}GoalA
3.2 if B then Sub\textsuperscript{2}GoalB
3.3 if C then Sub\textsuperscript{2}GoalC
3.4 if D then Sub\textsuperscript{2}GoalD
4. if not bla3 and bla2 then SubGoal4
5. if bla1 and bla3 and bla8 then SubGoal5
6. if blabla then SubGoal6
7. if bla2 or ( bla3 and not bla7 ) then SubGoal7
Watering behavior:

- Find & take a can
- Fill the can
- Go next to a dry bed
- Water the bed
- Empty the can
- Put down the can

Goal: the garden is watered
Virtual mind
Behavior decomposition

- Highest priority rule first

1. if garden_watered and cleaned then COMMIT
2. if garden_watered then subGoal_Clean
3. if not_hold_any_can then subGoal_FindTakeCan
4. if can_in_hands and empty then subGoal_FillUpTheCan
5. if know_about_dry_bed & not_stand_nextTo_theBed then subGoal_GoThere
6. if stand_nextTo_theBed and theBad_dry then atomicWatering

- Robust to dynamic changes in the world
Virtual mind
Behavior decomposition problems

1. Actions ordering
2. Timeout problem / Alternatives
3. Transition behavior
4. Context actions

And more...

5. Behavior overswitching (commitment)
6. Parallel behaviors
7. Episodes

...
1. Actions ordering

1. if garden_watered and cleaned then COMMIT
2. if garden_watered then subGoal_Clean

3. if not_hold_any_can then subGoal_FindTakeCan
4. if can_in_hands and empty then subGoal_FillUpTheCan

5. if know_about_dry_bed and not_stand_nextTo_theBed then subGoal_GoThere

6. if stand_nextTo_theBed and theBad_dry then atomicWatering
Virtual mind
Behavior decomposition problems (1/4)

1. Actions ordering

1. if garden_watered and cleaned then COMMIT
2. if garden_watered then subGoal_Clean

3. if not_hold_any can_or_rake then
   subGoal_FindTake CanAndRake
4. if can_in_hands and empty then subGoal_FillUpTheCan

5. if know_about_dry_bed and not_stand_nextTo_theBed then subGoal_GoThere

6. if stand_nextTo_theBed and theBad_dry then atomicWatering
2. Timeout problem / Alternatives

1. if garden_watered and cleaned then COMMIT
2. if garden_watered then subGoal_Clean
3. if not_hold_any_can then subGoal_FindTakeCan
4. if can_in_hands and empty then subGoal_FillUpTheCan
5. if know_about_dry_bed and not_stand_nextTo_theBed then subGoal_GoThere
6. if stand_nextTo_theBed and theBad_dry then atomicWatering
3. Transition behavior

1. if garden_watered and cleaned then COMMIT
2. if garden_watered then subGoal_Clean

3. if not_hold_any_can then subGoal_FindTakeCan
4. if can_in_hand and empty then subGoal_FillUpTheCan

5. if know_about_dry_bed and not_stand_nextTo_theBed then subGoal_GoThere

6. if stand_nextTo_theBed and theBad_dry then atomicWatering
3. Transition behavior

1. if hungry then GoHomeAndEatSomething
2. if garden_watered and cleaned then COMMIT
3. if garden_watered then subGoal_Clean

4. if not_hold_any_can then subGoal_FindTakeCan
5. if can_in_hands and empty then subGoal_FillUpTheCan

6. if know_about_dry_bed and not_stand_nextTo_theBed then subGoal_GoThere

7. if stand_nextTo_theBed and theBad_dry then atomicWatering
Virtual mind

Behavior decomposition problems (3/4)

3. Transition behavior

1. if hungry then GoHomeAndEatSomething
2. if garden_watered and cleaned then COMMIT
3. if garden_watered then subGoal_Clean
4. if not_hold_any_can then subGoal_FindTakeCan
5. if can_in_hands and empty then subGoal_FillUpTheCan
6. if know_about_dry_bed and not_stand_nextTo_theBed then subGoal_GoThere
7. if stand_nextTo_theBed and theBad_dry then atomicWatering
4. **Context actions**

1. if garden_watered and cleaned then COMMIT
2. if garden_watered then subGoal_Clean

3. if not_hold_any_can then subGoal_FindTakeCan
4. if can_in_hands and empty then subGoal_FillUpTheCan

5. if know_about_dry_bed & not_stand_nextTo_theBed then subGoal_GoThere

6. if stand_nextTo_theBed and theBad_dry then atomicWatering
Virtual mind
Behavior decomposition challenges

Looks easy?

- You may try to devise robust behavior for a guy who needs to get abroad... behavior for several days
  - Simulate needs (hunger, drowsiness)
  - Planning actions (he needs visa, buy some things for a trip, email his wife, buy a ticket, ...)
  - Maintainable design?
  - Generalization?
More challenges

- Learning behavior from observations
- Motivation/goal prediction of others
- Episodic memory
- Emotions
Virtual Human
Components

Virtual Mind

1. What it is?
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4. Combining reactive behavior and planning?
Virtual mind
Conceptual frameworks

- If-than rules
  - (h) FSMs, POSH / Behavior trees
- And-Or trees / “HTN”
- BDI
  - AgentSpeak

...
Virtual minds
Conceptual frameworks

- (h)FSMs
  - Actions in states
  - Problem is transition specification ... $O(N^2)$
  - Gardener
    - States
      - finding-can, going-to-water-bed, watering, cleaning-up
      $\Rightarrow$ 12 transitions
  - We may easily provide Transition behaviors!
Behavior trees

- AI design pattern in computer games
- Similar to if-then trees
- Selectors, Sequences, Decorators
  - Decorators are used to plugged additional behavior to action selection, i.e., solving timeouts
Virtual minds
Conceptual frameworks

- And-Or trees
  - And nodes -> behavior sequence
  - Or nodes -> alternative behaviors

- M. Cavazza, Video
Virtual minds
Conceptual frameworks

- BDI – AgentSpeak
  - Bratman
  - Beliefs, Desire, Intentions
  - Deliberation + Means-end reasoning
Virtual minds
Conceptual frameworks
Virtual minds

Conclusion

- IF-Then rules + (h)FSMs + Behavior trees works as best
- Just plain C/C++/Java usually suffice
- Nobody has done evaluation on big worlds where virtual humans have to live for months...
Virtual Human Components

Virtual Mind

1. What it is?
2. Typical problems
3. Conceptual frameworks for implementations
4. Combining reactive behavior and planning?
   ▪ Just my idea... never tried nor formalized
Let’s address action-ordering-problem

- let’s use Strips-like planning for subbehaviors that needs that!
- We’re just planning subbehavior

⇒ We may create simple planning domain, that are guaranteed to be evaluated fast by the planner
- Create behavior out of actions
Virtual mind
Planning reactive behavior?

- Having our gardener and weeding...
- Actions:
  - Go_Can, Go_Rake, Pick_Can, Pick_Rake, Fill_Can, Go_WaterBed, Water, Weed, CleanUp
- Atoms (set representation):
  - Somewhere, At_Rake, At_Can, Has_Rake, Has_Can, At_WaterBed, Wed, Waterred, CleanedUp
  - + some negative counterparts
Let’s say our planner has produced this plan:

1. Go_Can
2. Pick_Can
3. Go_Rake
4. Pick_Rake
5. Fill_Can
6. Go_WaterBed
7. Weed
8. Water
9. CleanUp
Actions has preconds/effects:

1. **at_can** & **not_has_can**  -> **Go_Can**  -> **at_can**
2. **at_can** & **not_has_can**  -> **Pick_Can**  -> **has_can**
3. **at_rake** & **not_has_rake**  -> **Go_Rake**  -> **at_rake**
4. **at_rake** & **not_has_rake**  -> **Pick_Rake**  -> **has_rake**
5. **has_can** & **can_empty**  -> **Fill_Can**  -> **can_filled**
6. **at_wbed** & **not_wed** & **has_rake**  -> **Go_WBed**  -> **at_wbed**
7. **at_wbed** & **not_wed** & **has_rake**  -> **Weed**  -> **wed**
8. **at_wbed** & **not_watered** & **has_can** & **can_filled**  -> **Water**  -> **watered**
9. **wed** & **watered**  -> **CleanUp**  -> **cleaned_up**
Reverse the order:

1. **wed & watered** -> CleanUp -> cleaned_up
2. **at_wbed & not_watered & has_can & can_filled** -> Water -> watered
3. **at_wbed & not_wed & has_rake** -> Weed -> wed
4. **has_can & can_empty** -> Fill_Can -> can_filled
5. **at_rake & not_has_rake** -> Pick_Rake -> has_rake
6. **at_can & not_has_can** -> Pick_Can -> has_can
7. **at_rake & not_has_rake**
8. **at_can & not_has_can**
9. **at_can & not_has_can**
Add comulated atoms (...ignore movement) and perform the behavior!

1. has_can & has_rake & can_filled & wed & watered
   -> CleanUp -> cleaned_up
2. has_rake & wed & at_wbed & not_watered & has_can & can_filled
   -> Water  -> watered
3. has_can & can_filled & at_wbed & not_wed & has_rake
   -> Weed   -> wed
   -> Go_Wbed -> at_wbed
4. has_rake & has_can & can_empty
   -> Fill_Can -> can_filled
5. has_rake & has_can & can_empty
   -> Fill_Can -> can_filled
6. has_can & at_rake & not_has_rake
   -> Pick_Rake -> has_rake
7. has_can
   -> Go_Rake  -> at_rake
8. at_can & not_has_can
   -> Pick_Can -> has_can
   -> Go_Can  -> at_can
Conclusion
Virtual human challenges

- Virtual world
  - Automatic navigation graph construction, Quick dynamic path planning with formations
- Virtual body
  - Animation controllers, Emotions, Natural language processing
- Virtual mind
  - Combine reactiveness with automatic planning, perhaps CSPs, Episodic memory, Emotions, ...
Thank you for your attention!

Questions?