

An assistive handwashing system with emotional intelligence

Luyuan Lin

University of Waterloo

Supervisor:
Jesse Hoey

July 22, 2014

Agenda

1 Problem Statement

- Motivation
- Objectives

2 Basic Concepts

- Affect Control Theory (ACT)
- The BayesACT Framework

3 Solution: System Design

- Components
- Coordination between components

4 Experimental Results

5 Discussion

- Contribution
- Future Work

The COACH system

- works well for some persons, but not as well for others
- only considers functional states of users

The COACH system

- works well for some persons, but not as well for others
- only considers functional states of users

Using Emotional Intelligence in Assitive Systems

Problem Statement - Objectives

To augment the COACH system with an emotional reasoning engine so that the augmented system:

- is designed in a portable and extensible way
- runs in real-time from the perspective of the user group
- provides a level of functional assistance
- produces the prompts according to the emotional state of a user

Affect Control Theory (ACT)

- represents emotions as EPA vectors
- describes social events by an Actor-Behaviour-Object grammar
- “fundamentals” of identities and behaviours; shared between people within a same culture
- “transient impressions”: emotional feelings caused by a specific event

Affect Control Theory (ACT)

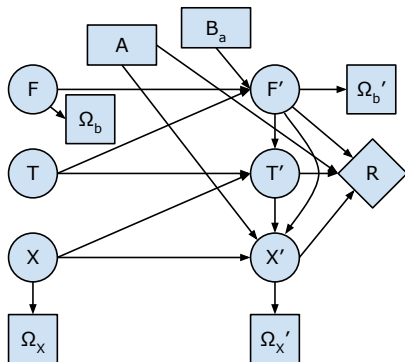
- represents emotions as EPA vectors
- describes social events by an Actor-Behaviour-Object grammar
- “fundamentals” of identities and behaviours; shared between people within a same culture
- “transient impressions”: emotional feelings caused by a specific event

The ACT Principal

Actors work to experience transient impressions that are consistent with their fundamental sentiments.

Concepts - BayesACT

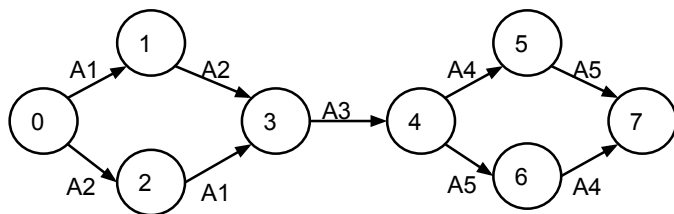
- A Bayesian version of the ACT theory
- Extends the ACT with POMDP model



- States $S = \{F, T, X\}$, where $F = \{F_{ij}\}$, $T = \{T_{ij}\}$, $i \in \{a, b, c\}$, $j \in \{e, p, a\}$
- Note: F_c denotes the agent's belief of the client's identity
- Observations $\Omega = \{\Omega_X, \Omega_b\}$
- Actions $\{A, B_a\}$
- Calculate $\{A, B_a\}$ basing on $\{F, T, X\}$

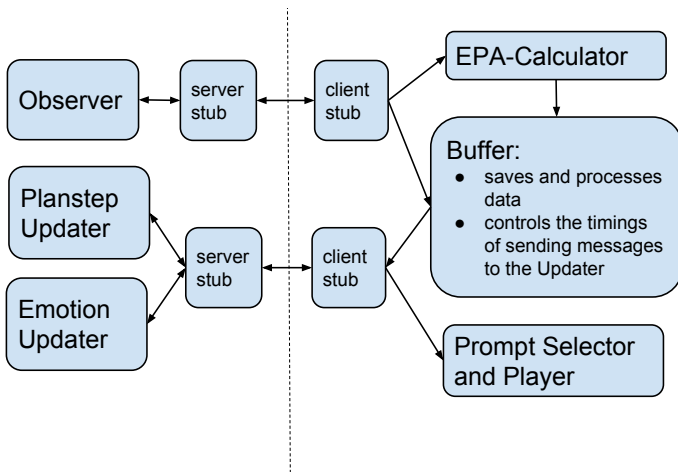
Solution - Representing “Functional States”

Planstep Definition and Update Diagram



- Eight plansteps: (0) “off/dirty/dry”, (1) “on/dirty/dry”, (2) “off/soapy/dry”, (3) “on/soapy/dry”, (4) “on/clean/wet”, (5) “off/clean/wet”, (6) “on/clean/dry”, (7) “off/clean/dry”
- Five behaviours: A1 to A5 are “turn on water”, “put on soap”, “rinse hands”, “turn off water”, and “use towel”, respectively.

Solution - Overview



Solution - the Planstep and Emotion Updater

Use the BayesACT framework in the handwashing scenario

- Recall: BayesACT includes states $S = \{X, F, T\}$, observations $\Omega = \{\Omega_x, \Omega_b\}$, and agent actions $\{A, B_a\}$

Solution - the Planstep and Emotion Updater

Use the BayesACT framework in the handwashing scenario

- Recall: BayesACT includes states $S = \{X, F, T\}$, observations $\Omega = \{\Omega_x, \Omega_b\}$, and agent actions $\{A, B_a\}$
- In our hand-washing system, $X = \{X_{turn}, X_{ps}, X_{aw}, X_{bahav}\}$

Solution - the Planstep and Emotion Updater

Use the BayesACT framework in the handwashing scenario

- Recall: BayesACT includes states $S = \{X, F, T\}$, observations $\Omega = \{\Omega_x, \Omega_b\}$, and agent actions $\{A, B_a\}$
- In our hand-washing system, $X = \{X_{turn}, X_{ps}, X_{aw}, X_{bahav}\}$
- Ω_x gives evidence to the system about X

Solution - the Planstep and Emotion Updater

Use the BayesACT framework in the handwashing scenario

- Recall: BayesACT includes states $S = \{X, F, T\}$, observations $\Omega = \{\Omega_x, \Omega_b\}$, and agent actions $\{A, B_a\}$
- In our hand-washing system, $X = \{X_{turn}, X_{ps}, X_{aw}, X_{bahav}\}$
- Ω_x gives evidence to the system about X
- Ω_b gives evidence to the system about f_b . The “confidence” of Ω_b is specified by γ , which is the variance of a normal (Gaussian) distribution.

Solution - the Planstep and Emotion Updater

Use the BayesACT framework in the handwashing scenario

- Recall: BayesACT includes states $S = \{X, F, T\}$, observations $\Omega = \{\Omega_x, \Omega_b\}$, and agent actions $\{A, B_a\}$
- In our hand-washing system, $X = \{X_{turn}, X_{ps}, X_{aw}, X_{behav}\}$
- Ω_x gives evidence to the system about X
- Ω_b gives evidence to the system about f_b . The “confidence” of Ω_b is specified by γ , which is the variance of a normal (Gaussian) distribution.
- Compute X'_{ps} based on observation Ω_x and $\{X_{ps}, X_{behav}, X_{aw}, F, T\}$

Solution - the Planstep and Emotion Updater

Use the BayesACT framework in the handwashing scenario

- Recall: BayesACT includes states $S = \{X, F, T\}$, observations $\Omega = \{\Omega_x, \Omega_b\}$, and agent actions $\{A, B_a\}$
- In our hand-washing system, $X = \{X_{turn}, X_{ps}, X_{aw}, X_{behav}\}$
- Ω_x gives evidence to the system about X
- Ω_b gives evidence to the system about f_b . The “confidence” of Ω_b is specified by γ , which is the variance of a normal (Gaussian) distribution.
- Compute X'_{ps} based on observation Ω_x and $\{X_{ps}, X_{behav}, X_{aw}, F, T\}$
- A denotes the propositional content of a system message; B_a denotes how the message should be expressed

Solution - the EPA-Calculator

- Essentially an “Affect Recognition” problem
- Learns/ Calculates affective interpretations from user behaviours

Solution - the EPA-Calculator

- Essentially an “Affect Recognition” problem
- Learns/ Calculates affective interpretations from user behaviours
- Feature Selection
 - analysis on facial expressions and speeches
 - application scenario and user-group constraints

Solution - the EPA-Calculator

- Essentially an “Affect Recognition” problem
- Learns/ Calculates affective interpretations from user behaviours
- Feature Selection
 - analysis on facial expressions and speeches
 - application scenario and user-group constraints
- Calculate P, A using piecewise linear interpolation method
 - The average distance between the user's two hands in a set of n neighbouring frames is scaled to P
 - The average distance the user's hands move between n neighbouring frames is scaled to A

Solution - the EPA-Calculator

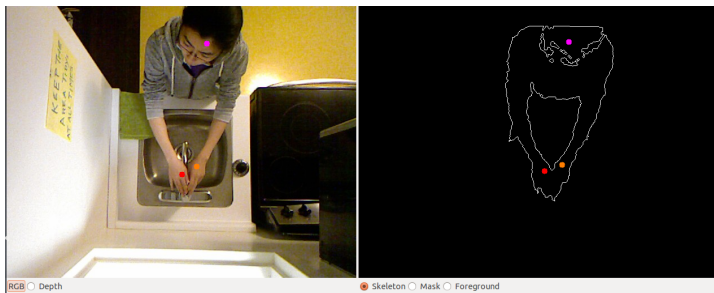
- Essentially an “Affect Recognition” problem
- Learns/ Calculates affective interpretations from user behaviours
- Feature Selection
 - analysis on facial expressions and speeches
 - application scenario and user-group constraints
- Calculate P, A using piecewise linear interpolation method
 - The average distance between the user's two hands in a set of n neighbouring frames is scaled to P
 - The average distance the user's hands move between n neighbouring frames is scaled to A
- Temporally smoothing in the Buffer

Solution - the Observer

- Step 1: Get the locations of the user's hands
 - utilize Czarnuch and Mihailidis's body tracker [?]
 - the tracker obtains body parts locations from the depth information of images taken from an overhead perspective
 - the tracker was trained using partially labeled, unbalanced data, and is configurable and re-trainable

Solution - the Observer

- Step 1: Get the locations of the user's hands
 - utilize Czarnuch and Mihailidis's body tracker [?]
 - the tracker obtains body parts locations from the depth information of images taken from an overhead perspective
 - the tracker was trained using partially labeled, unbalanced data, and is configurable and re-trainable



Solution - the Observer cont.

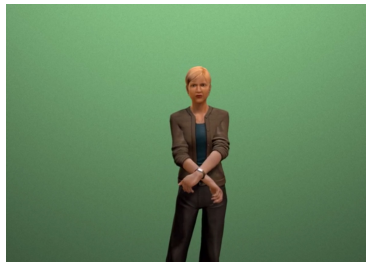
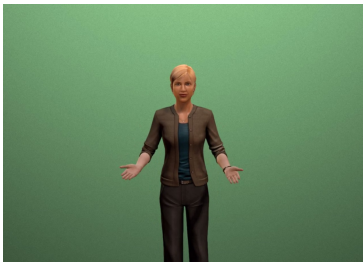
- Step 1: Get the locations of the user's hands
 - utilize Czarnuch and Mihailidis's body tracker [?]
 - the tracker obtains body parts locations from the depth information of images taken from an overhead perspective
 - the tracker was trained using partially labeled, unbalanced data, and is configurable and re-trainable
- Step 2: Map locations to user behaviours
 - compare hands locations with object positions
 - objects: the left-tap, the right-tap, the soap, the water-flow, the towel
 - observation noise handled by the observation function in the Reasoning Engine

Solution - the Observer cont.

- Step 1: Get the locations of the user's hands
 - utilize Czarnuch and Mihailidis's body tracker [?]
 - the tracker obtains body parts locations from the depth information of images taken from an overhead perspective
 - the tracker was trained using partially labeled, unbalanced data, and is configurable and re-trainable
- Step 2: Map locations to user behaviours
 - compare hands locations with object positions
 - objects: the left-tap, the right-tap, the soap, the water-flow, the towel
 - observation noise handled by the observation function in the Reasoning Engine
- Serves as an Observer server
 - with the help of the Buffer

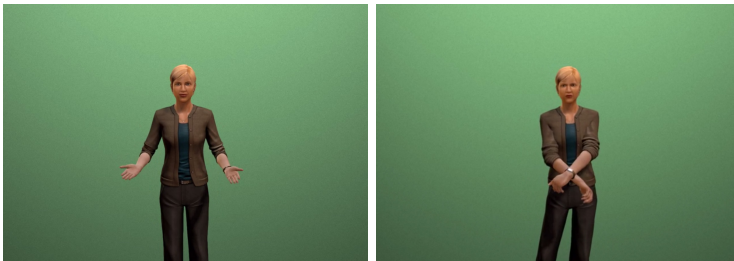
Solution - the Output Part

- The prompt dataset: the audio-visual prompts generated and evaluated in Malhotra's study [?]
 - created 30 video clips using the USC Virtual Human Toolkit
 - EPA values of videos evaluated by human raters
 - the participants' answers are consistent with each other



Solution - the Output Part

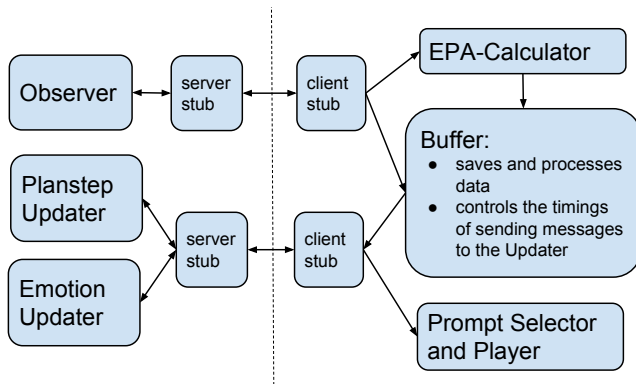
- The prompt dataset: the audio-visual prompts generated and evaluated in Malhotra's study [?]
 - created 30 video clips using the USC Virtual Human Toolkit
 - EPA values of videos evaluated by human raters
 - the participants' answers are consistent with each other



- A proper prompt is selected as the final prompt if it:
 - has the same propositional labels as the desired prompt
 - has the closest emotional (EPA) values as the desired prompt

Solution - Coordination between components

- The system is designed with independent components.



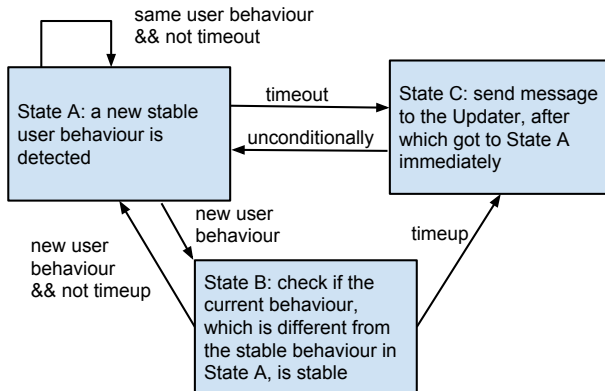
- How to coordinate between the components?
 - timings of sending request and response messages?

Solution - The Buffer

- Between the Observer, the EPA-Calc, and the Reasoning Engine

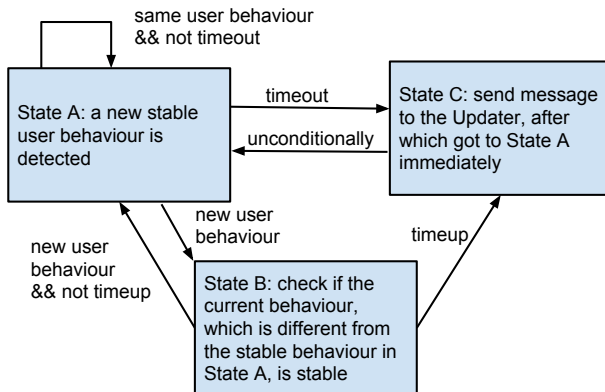
Solution - The Buffer

- Between the Observer, the EPA-Calc, and the Reasoning Engine
- Controls timings of sending messages



Solution - The Buffer

- Between the Observer, the EPA-Calc, and the Reasoning Engine
- Controls timings of sending messages



- Smooths EPA values calculated by the Calculator

Experiments - Parameter values used in laboratory experiments

Param.	Value	Defined in which component
n	10	EPA-Calc
$distance$	$\{-\infty, 0, 8, 40, 128, 160, +\infty\}$	EPA-Calc
$potency$	$\{-4.3, -4.3, 0, 1, 2, 4.3, 4.3\}$	EPA-Calc
$difference$	$\{-\infty, 0, 3.5, 17.5, 35, 70, +\infty\}$	EPA-Calc
$activity$	$\{-4.3, -4.3, -2, -1, 0, 4.3, 4.3\}$	EPA-Calc
$alpha$	0	Buffer
$timeout$	300	Buffer
$timeup$	1	Buffer
β_a^0	0.001	Updater
β_c^0	2.0	Updater
γ	(100000, 1.0, 0.5)	Updater
N	2000	Updater
f_a^0	[1.5, 0.51, 0.45]	Updater
f_c^0	Different in each test	Updater

Experiments - Latency of the system

Experiments conducted on the system show that an average latency of

- 46.79ms is caused by the Observer component of the system
- 0.009ms caused by the Buffer
- 1.65s caused by the Updater

The overall average latency of the system is around 1.70s:
the system runs in real-time from the perspective of its user group

Experiments - Two laboratory tests

Two laboratory tests

- link to test #1
- link to test #2

Another 15 tests were also run. Results are in the Appendix.

Experiments - Conclusion

- Functionality performance
 - sometimes false positively recognizes an user behaviour
 - is able to produce propositionally useful system prompts in general

Experiments - Conclusion

- Functionality performance
 - sometimes false positively recognizes an user behaviour
 - is able to produce propositionally useful system prompts in general
- Emotionality performance

No.	mean of be-hav.	init of f_c	mean of f_c	mean of prompt
#1	[0, 1.32, -1.3]	[1.61, 0.84, -0.87]	[2.8, 1.03, -0.73]	[1.62, 0.32, 0.75]
#2	[0, 0.77, -1.74]	[-0.64, -0.43, -1.81]	[1.13, -0.43, -1.47]	[1.53, 0.66, 0.08]

Experiments - Conclusion

- Functionality performance
 - sometimes false positively recognizes an user behaviour
 - is able to produce propositionally useful system prompts in general
- Emotionality performance

No.	mean of be- hav.	init of f_c	mean of f_c	mean of prompt
#1	[0, 1.32, -1.3]	[1.61, 0.84, -0.87]	[2.8, 1.03, -0.73]	[1.62, 0.32, 0.75]
#2	[0, 0.77, -1.74]	[-0.64, -0.43, -1.81]	[1.13, -0.43, -1.47]	[1.53, 0.66, 0.08]

Generally, for tests the actor acted more powerfully and more actively:

- larger P and larger A values were computed for user behaviours
- larger P and larger A values were achieved for f_c 's
- smaller P and larger A values were produced for prompts, among which the differences between A values are more obvious

Recall - Objective of this thesis

- is designed in a portable and extensible way
- runs in real-time from the perspective of the user group
- provides at least a level of functional assistance of as high quality as the COACH
- is able to tune the prompts in some way according to the emotional state of a user

Contribution

Contribution

- Reviewed previous work in all the four aspects of emotional intelligence

Contribution

- Reviewed previous work in all the four aspects of emotional intelligence
- Designed and implemented a prototypical hand-washing system that
 - is extensible and portable
 - runs in real-time from the perspective of the user group
 - provides a level of functional assistance
 - produces system prompts that have encoded to some extent the emotional state of the user

Contribution

- Reviewed previous work in all the four aspects of emotional intelligence
- Designed and implemented a prototypical hand-washing system that
 - is extensible and portable
 - runs in real-time from the perspective of the user group
 - provides a level of functional assistance
 - produces system prompts that have encoded to some extent the emotional state of the user
- Tests also indicated that user behaviours with higher P and higher A values may lead to f_c 's with higher P and higher A values and system prompts with lower P and higher A values

Future Work

- Improve the EPA-Calculator
- Improve the prompt generation process
- Improve the Planstep- and Emotion- Updater
- Conduct clinical trials for the system

Acknowledgement

This work is based on previous works of:

- 1 The bayesact paper
- 2 The tracker paper.
- 3 The survey paper.

I'd like to take this opportunity to thank:

- Jesse Hoey
- James Tung and Peter van Beek
- Xiao Yang, Chengbo Li and Enxun Wei
- My family and friends

Thank you!

- Questions?
- Comments?

Model formulation

Model formulation

- The deflection $\phi(F, T)$ between F and T :

$$\phi(f, t) \propto e^{-(f'-t')\Sigma^{-1}(f-t)} \quad (1)$$

Model formulation

- The deflection $\phi(F, T)$ between F and T :

$$\phi(f, t) \propto e^{-(f' - t')\Sigma^{-1}(f - t)} \quad (1)$$

- The probability of a post-action fundamental sentiment f' :

$$Pr(f'|f, t, x, b_a, \phi) \propto e^{-\phi(f', t') - \xi(f', f, b_a, x)} \quad (2)$$

where t' can be computed from $\{f', t, x\}$ by empirically derived prediction equations of ACT.

Model formulation

- The deflection $\phi(F, T)$ between F and T :

$$\phi(f, t) \propto e^{-(f' - t')\Sigma^{-1}(f - t)} \quad (1)$$

- The probability of a post-action fundamental sentiment f' :

$$Pr(f'|f, t, x, b_a, \phi) \propto e^{-\phi(f', t') - \xi(f', f, b_a, x)} \quad (2)$$

where t' can be computed from $\{f', t, x\}$ by empirically derived prediction equations of ACT.

- $Pr(x'|x, f', t', a)$: how the application progresses

Model formulation

- The deflection $\phi(F, T)$ between F and T :

$$\phi(f, t) \propto e^{-(f'-t')\Sigma^{-1}(f-t)} \quad (1)$$

- The probability of a post-action fundamental sentiment f' :

$$Pr(f'|f, t, x, b_a, \phi) \propto e^{-\phi(f', t') - \xi(f', f, b_a, x)} \quad (2)$$

where t' can be computed from $\{f', t, x\}$ by empirically derived prediction equations of ACT.

- $Pr(x'|x, f', t', a)$: how the application progresses
- $Pr(\omega_b|f)$ and $Pr(\omega_x|x)$: observation functions for the client behaviour sentiment and system state

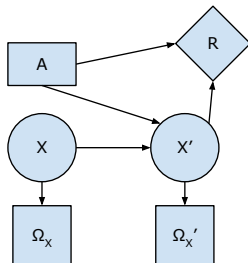
Update X'_{ps} based on Ω_x and $\{X_{ps}, X_{behav}, X_{aw}, F, T\}$

- *SampleXVar()* and *evalSampleXVar()*
- Pseudocode of *SampleXVar()* (on next page)
- $Pr : X_{behav} \rightarrow \Delta(\Omega_x)$ used in *evalSampleXVar()*

Update X'_{ps} based on Ω_x and $\{X_{ps}, X_{behav}, X_{aw}, F, T\}$ cont.

```
1: if Deflection(F, T) is high then
2:   threshold = high
3: else
4:   threshold = low
5: end if
6: if aw high then
7:   if prompted then
8:     if random_prob() < threshold then
9:       aw = low and not moving forward
10:    else if prompt wrong then
11:      aw = low and not moving forward
12:    else if likely then
13:      moving forward
14:    else if random_prob() < threshold then
15:      aw = low and not moving forward
16:    end if
17:  else
18:    if random_prob() < threshold then
19:      aw = low and not moving forward
20:    else
21:      aw stays high and moving forward
22:    end if
23:  end if
24: else
25:   if prompted then
26:     if random_prob() > threshold and
27:       prompt correct then
28:       move on and aw high
29:     else
30:       unlikely: aw high and not moving
31:       forward
32:     end if
33:   else
34:     unlikely: aw high and moving forward
35:   end if
36: end if
```

Partially Observable Markov Decision Process (POMDP)



- A timeslice of a POMDP process
- Variables: $\{ X, A, \Omega_X \}$
- $Pr : X \rightarrow \Delta(\Omega_X)$,
 $Pr : X \times A \rightarrow \Delta(X)$
- Reward Function: $R(A, X')$