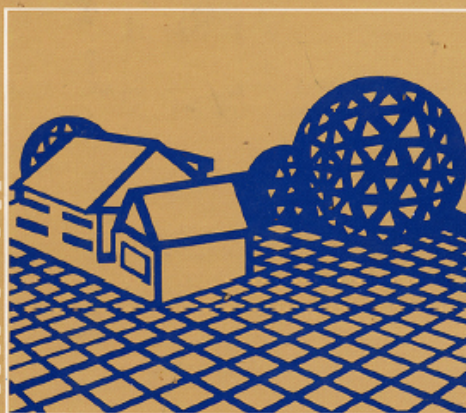
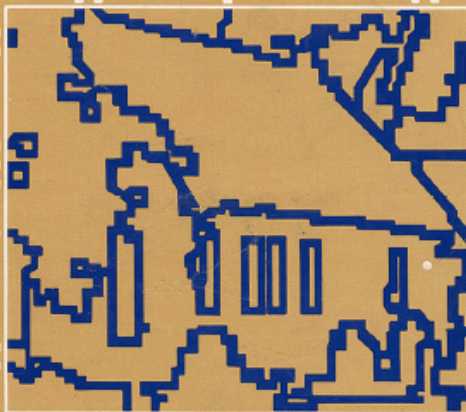


COMPUTER VISION

DANA H. BALLARD • CHRISTOPHER M. BROWN





D:095 H:333 V:163

FC:62443

Different ways to make a sandwich

	1	2	3	4	5	6	7	8	9	10
BT	abc									
PLF		a	c		b					
JLF		bc				a				
KH			ab	c						
POB				a	c	b				
JOB				b		c	a			
PLO					a				b	c
JLO									c	ab
KT							c	ab		
FB							b	c	a	

Routines



```
locate bread  
remember loc_loaf  
puthand right  
pickup right  
fixate -0.1 -0.2 0.78  
remember loc_bread1  
puthand right  
turnhand right 0 0 90  
dropoff right  
turnhand right 0 0 0
```

Routine Segmentation

```
locate bread
remember loc_loaf
puthand right
pickup right
fixate -0.1 -0.2 0.78
remember loc_bread1
puthand right
turnhand right 0 0 90
dropoff right
turnhand right 0 0 0
fixate loc_loaf
puthand right
pickup right
fixate 0.1 -0.2 0.78
remember loc_bread2
puthand right
turnhand right 0 0 90
dropoff right
turnhand right 0 0 0
locate jar-lid
remember loc_jarlid
puthand right
pickup right
fixate -0.40 -0.2 0.65
remember loc_jarlid_on_table
puthand right
dropoff right
locate pbilid
remember loc_bottleid
puthand right
pickup right
fixate -0.3 -0.2 0.65
remember loc_bottleid_on_table
puthand right
dropoff right
locate khandle
remember loc_knife
puthand right
pickup right
locate pbbottle
remember loc_bottle
puthand right
fixate -0.1 -0.2 0.78
puthand right
loc_bottle
fixate -0.1 -0.2 0.78
puthand right
locate jar
remember loc_jar
puthand right
fixate 0.1 -0.2 0.78
puthand right
fixate loc_knife
puthand right
dropoff right
locate jar
fixate loc_bread1
puthand right
pickup right
turnhand right 0 0 -90
fixate loc_bread2
puthand right
dropoff right
fixate loc_jarlid_on_table
puthand right
pickup right
fixate loc_bottleid
puthand right
dropoff right
fixate loc_jarlid_on_table
puthand right
pickup right
fixate loc_jarlid
puthand right
dropoff right
fixate loc_bottleid
puthand right
dropoff right
```

```
locate bread
remember loc_loaf
puthand right
pickup right
fixate -0.1 -0.2 0.78
remember loc_bread1
puthand right
turnhand right 0 0 90
dropoff right
turnhand right 0 0 0
fixate loc_loaf
puthand right
pickup right
fixate 0.1 -0.2 0.78
remember loc_bread2
puthand right
turnhand right 0 0 90
dropoff right
turnhand right 0 0 0
locate jar-lid
remember loc_jarlid
puthand right
pickup right
fixate -0.40 -0.2 0.65
remember loc_jarlid_on_table
puthand right
dropoff right
locate khandle
remember loc_knife
puthand right
pickup right
locate jar
remember loc_jar
puthand right
fixate 0.1 -0.2 0.78
puthand right
locate pbilid
remember loc_bottleid
puthand right
pickup right
fixate -0.3 -0.2 0.65
remember loc_bottleid_on_table
puthand right
dropoff right
locate pbbottle
remember loc_bottle
puthand right
fixate -0.1 -0.2 0.78
puthand right
loc_bottle
fixate -0.1 -0.2 0.78
puthand right
locate jar
remember loc_jar
puthand right
fixate 0.1 -0.2 0.78
puthand right
fixate loc_bread1
puthand right
pickup right
turnhand right 0 0 -90
fixate loc_bread2
puthand right
dropoff right
fixate loc_knife
puthand right
dropoff right
locate jar
fixate loc_jarlid_on_table
puthand right
pickup right
fixate loc_jarlid
puthand right
dropoff right
fixate loc_bottleid
puthand right
dropoff right
```



Routine Segmentation



puthand right
dropoff right
locate pblid
remember loc_bottlelid
puthand right
pickup right
fixate -0.3 -0.2 0.65
remember loc_bottlelid_on_table
puthand right
dropoff right
locate khandle
remember loc_knife
puthand right
~~pickup right~~
locate pbbottle

puthand right
dropoff right
locate khandle
remember loc_knife
puthand right
pickup right
locate jar
remember loc_jar
puthand right
fixate 0.1 -0.2 0.78
puthand right
locate pblid
remember loc_bottlelid
~~puthand right~~
pickup right

Routine Segmentation



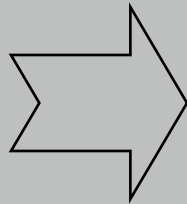
puthand right
dropoff right
locate pblid
remember loc_bottlelid
puthand right
pickup right
fixate -0.3 -0.2 0.65
remember loc_bottlelid_on_table
puthand right
dropoff right
locate khandle
remember loc_knife
puthand right
pickup right
locate pbbottle

puthand right
dropoff right
locate khandle
remember loc_knife
puthand right
pickup right
locate jar
remember loc_jar
puthand right
fixate 0.1 -0.2 0.78
puthand right
locate pblid
remember loc_bottlelid
puthand right
pickup right

Routine Segmentation

locate bread
remember_loc_loaf
puthand right
pickup right
fixate -0.1 -0.2 0.78
remember_loc_bread1
puthand right
turnhand right 0 0.90
droppoff right
turnhand right 0 0.0
fixate_loc_loaf
puthand right
pickup right
fixate 0.1 -0.2 0.78
remember_loc_bread2
puthand right
turnhand right 0 0.90
droppoff right
turnhand right 0 0.0
locate_jar-lid
remember_loc_jarlid
puthand right
pickup right
fixate -0.40 -0.2 0.65
remember_loc_jarlid_on_table
puthand right
droppoff right
locate pbill
remember_loc_bottleid
puthand right
pickup right
fixate -0.3 -0.2 0.65
remember_loc_bottleid_on_table
puthand right
droppoff right
locate khandle
remember_loc_knife
puthand right
pickup right
locate pbottle
remember_loc_bottle
puthand right
fixate -0.1 -0.2 0.78
puthand right
remember_loc_bottle
fixate -0.1 -0.2 0.78
puthand right
locate jar
remember_loc_jar
puthand right
fixate 0.1 -0.2 0.78
puthand right
fixate_loc_knife
puthand right
droppoff right
locate jar
fixate_loc_bread1
puthand right
pickup right
turnhand right 0 0-90
fixate_loc_bread2
puthand right
droppoff right
fixate_loc_bottleid_on_table
puthand right
pickup right
fixate_loc_bottleid
puthand right
droppoff right
fixate_loc_jarlid_on_table
puthand right
pickup right
fixate_loc_jarlid
puthand right
droppoff right

locate bread
remember loc_loaf
puthand right
pickup right
fixate -0.1 -0.2 0.78
remember loc_bread1
puthand right
turnhand right 0 0.90
droppoff right
turnhand right 0 0.0
fixate loc_loaf
puthand right
pickup right
fixate 0.1 -0.2 0.78
remember loc_bread2
puthand right
turnhand right 0 0.90
droppoff right
turnhand right 0 0.0
locate jar-lid
remember loc_jarlid
puthand right
pickup right
fixate -0.40 -0.2 0.65
remember loc_jarlid_on_table
puthand right
droppoff right
locate khandle
remember loc_knife
puthand right
pickup right
locate jar
remember loc_jar
puthand right
fixate 0.1 -0.2 0.78
puthand right
locate pbld
remember loc_bottleid
puthand right
pick up right
fixate -0.3 -0.2 0.65
remember loc_bottleid_on_table
puthand right
droppoff right
locate pbottle
remember loc_bottle
puthand right
fixate -0.1 -0.2 0.78
puthand right
puthand right loc_bottle
fixate -0.1 -0.2 0.78
puthand right
fixate loc_bread1
puthand right
pickup right
turnhand right 0 0-90
puthand right
fixate loc_knife
droppoff right
puthand right
locate jar
fixate loc_jarlid_on_table
puthand right
pickup right
fixate loc_jarlid
puthand right
droppoff right
fixate loc_bottleid_on_table
puthand right
pickup right
fixate loc_bottleid
puthand right
droppoff right



```

fixate locword
remember loc_word_jar
pathand right
pickup right
fixate 0.1 -0.2 0.78
remember loc_bread1
pathand right
turnhand right 0 0.90
dropoff right
fixate loc_bread1
fixate loc_bowl
pathand right
pickup right
fixate 0.1 -0.2 0.78
remember loc_bread2
pathand right
turnhand right 0 0.90
dropoff right
fixate loc_bread2
fixate loc_jar1
pathand right
remember loc_jar1
pickup right
fixate 0.40 -0.2 0.65
pathand right
dropoff right
locate pbid
remember loc_bottleid
pathand right
pickup right
fixate 0.3 -0.2 0.65
remember loc_bottleid_on_table
pathand right
dropoff right
locate khandie
remember loc_knife
pathand right
pickup right
locate pbottle
remember loc_bottle
pathand right
fixate -0.1 -0.2 0.78
pathand right
remember loc_bottle
fixate -0.1 -0.2 0.78
pathand right
locate jar
remember loc_jar
fixate 0.1 -0.2 0.78
pathand right
fixate loc_knife
pathand right
dropoff right
locate jar
fixate loc_bread1
pathand right
turnhand right 0 0.90
fixate loc_bread2
pathand right
dropoff right
fixate loc_bottleid_on_table
pathand right
pickup right
fixate loc_bottleid
pathand right
dropoff right
fixate loc_jarid_on_table
pathand right
pickup right
fixate loc_jarid
pathand right
dropoff right

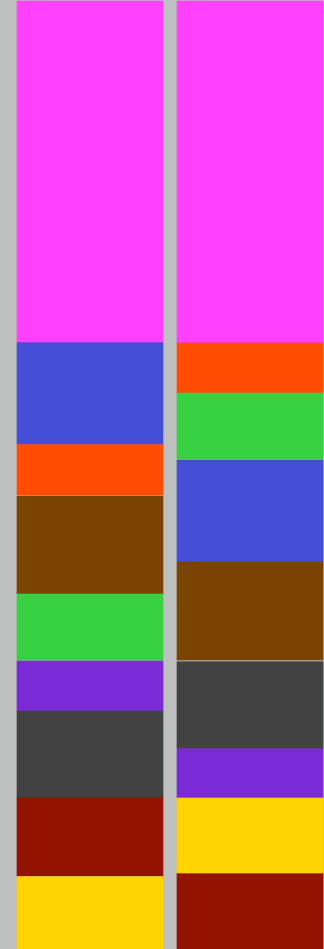
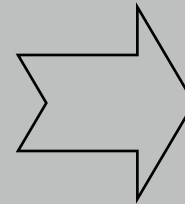
```

```

locate locard
remember loc_jar
puthand right
pickup right
fixate 0.1 -0.2 0.78
remember loc_bread1
puthand right
turnhand right 0 0 90
dropoff right
fixate loc_jar
puthand right
pickup right
fixate 0.1 -0.2 0.78
remember loc_bread2
puthand right
turnhand right 0 0 90
dropoff right
locate jar_loc
remember loc_jarloc
puthand right
pickup right
fixate -0.40 -0.2 0.65
remember loc_jarloc_on_table
puthand right
dropoff right

locate khandile
remember loc_knife
puthand right
pickup right
locate jar
remember loc_jar
puthand right
fixate 0.1 -0.2 0.78
remember loc_bottled
puthand right
pickup right
fixate -0.3 -0.2 0.65
remember loc_bottled_on_table
puthand right
dropoff right
locate bottle
remember loc_bottle
puthand right
fixate -0.1 -0.2 0.78
puthand right
puthand right loc_bottle
fixate -0.1 -0.2 0.78
puthand right
fixate loc_bread1
puthand right
pickup right
turnhand right 0 0 90
fixate loc_bread2
puthand right
dropoff right
fixate loc_knife
puthand right
dropoff right
locate jar
fixate loc_jarloc_on_table
puthand right
pickup right
fixate loc_jarloc
puthand right
dropoff right
remember loc_bottled_on_table
puthand right
pickup right
fixate loc_bottled
puthand right
dropoff right

```



Subtask Recognition

BreadOnTable	putting bread on table
PeanutButterLidOff	taking peanut butter lid off
JellyLidOff	taking jelly lid off
KnifeInHand	grabbing knife in hand
PeanutbutterOnBread	spreading peanut butter on bread
JellyOnBread	spreading jelly on bread
PeanutButterLidOn	putting peanut butter lid back on
JellyLidOn	putting jelly lid back on
KnifeOnTable	putting knife on table
FlipBread	flipping bread to make an sandwich

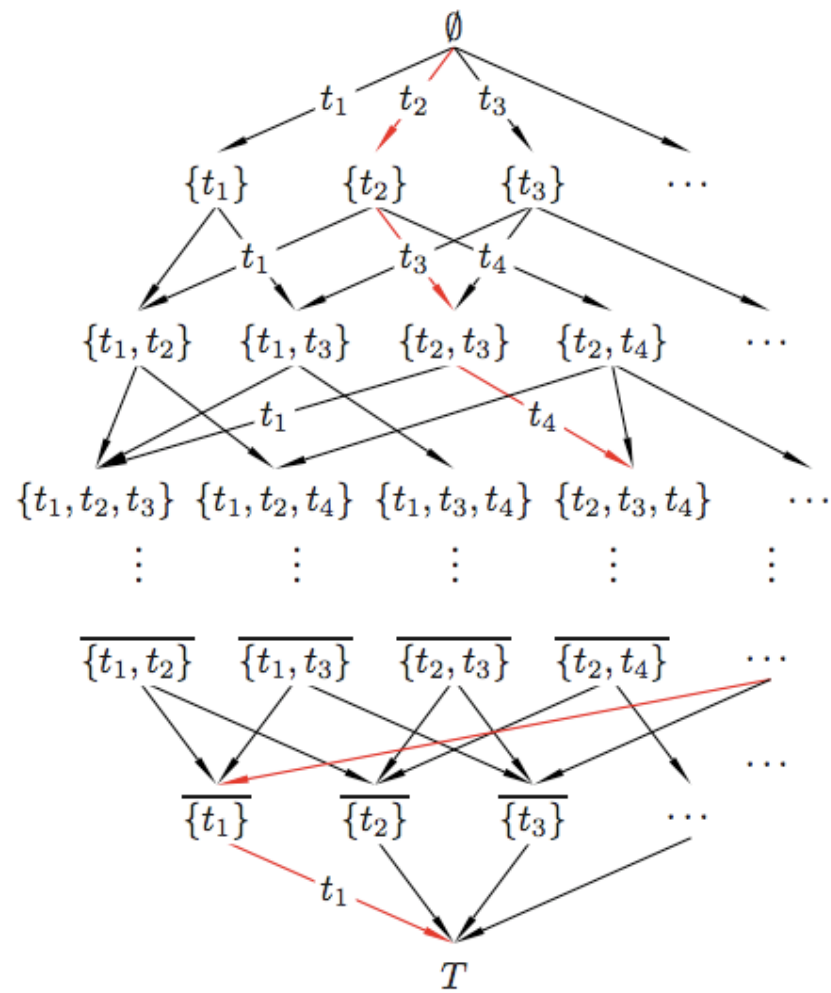
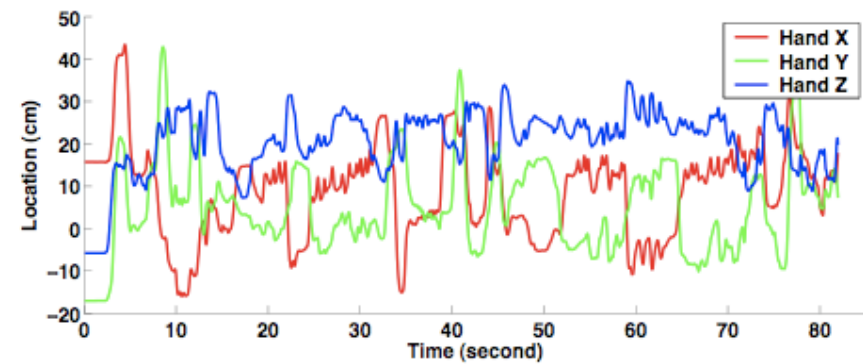
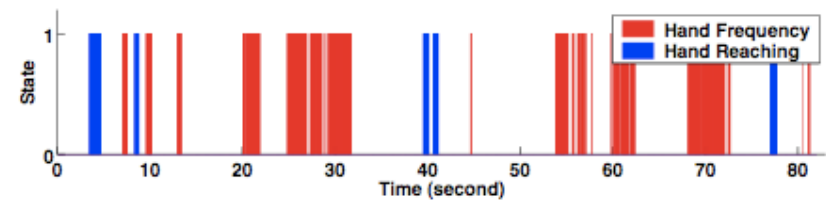


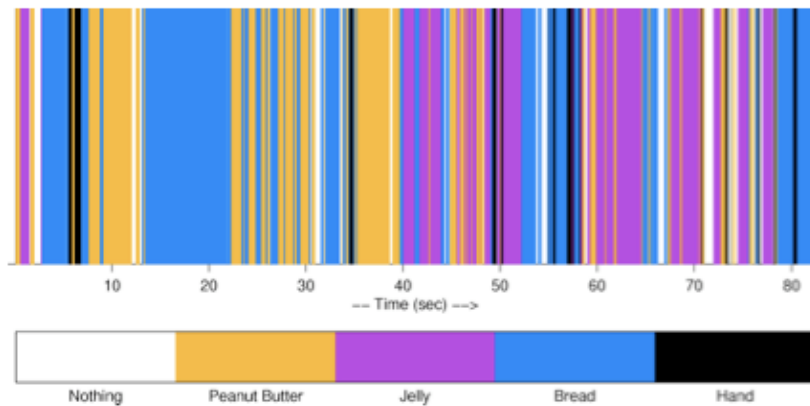
Figure 1. The Markovian task model.



(a) Raw hand location data



(b) Observed hand movement



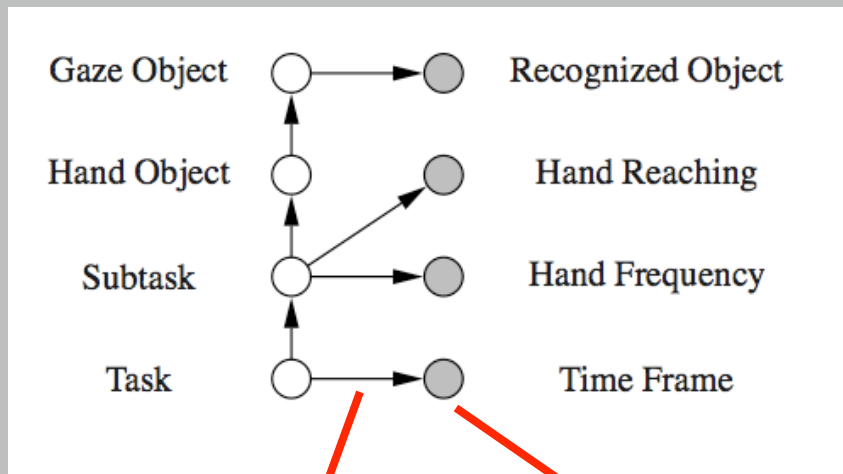
Hand; Data from 6 dof wrist sensor
Classified in REACHING(Blue) or
ROTATING (Red)

Eye : data from the fovea classified
based on color histogram

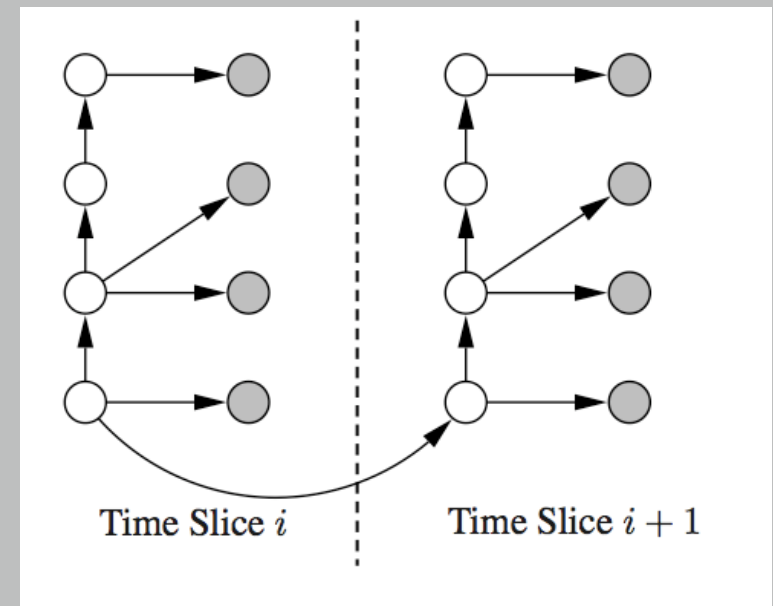
Raw data from a single
sandwich maker

$$\text{Task: } (\emptyset, \{t_1\}) \xrightarrow{p} (\{t_1\}, \{t_1, t_2\}) \xrightarrow{q} (\{t_1, t_2\}, \{t_1, t_2, t_4\})$$

Task node sub-structure:



$P(\text{Task}|\text{Evidence})$ $P(\text{Evidence})$

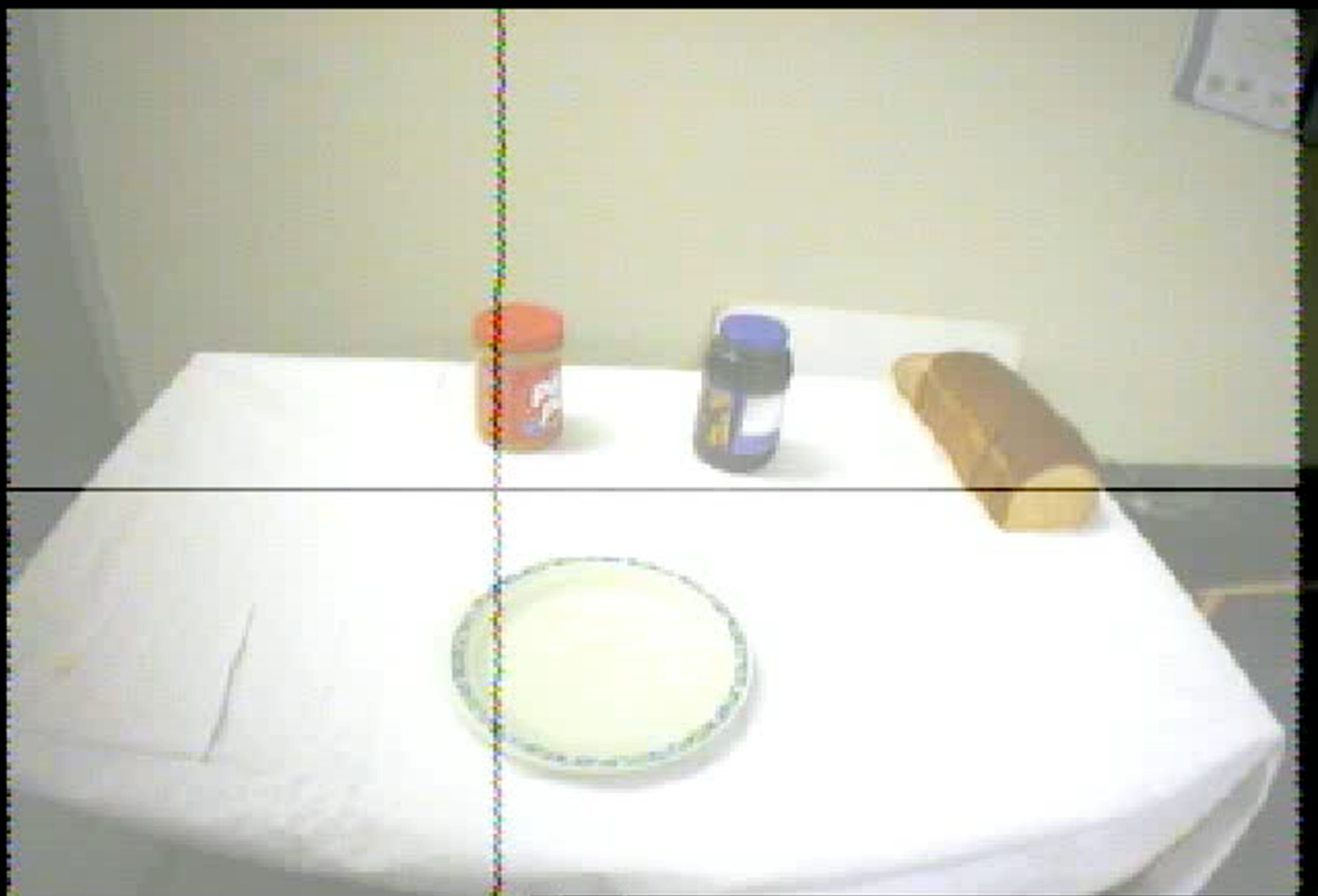


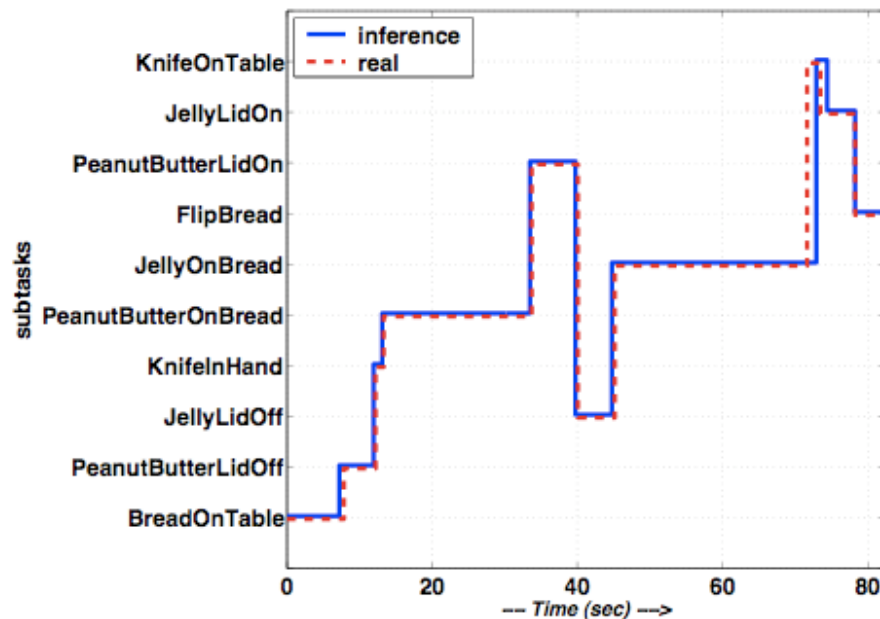
Dynamic Bayes Net for recognizing the steps in sandwich making

States:

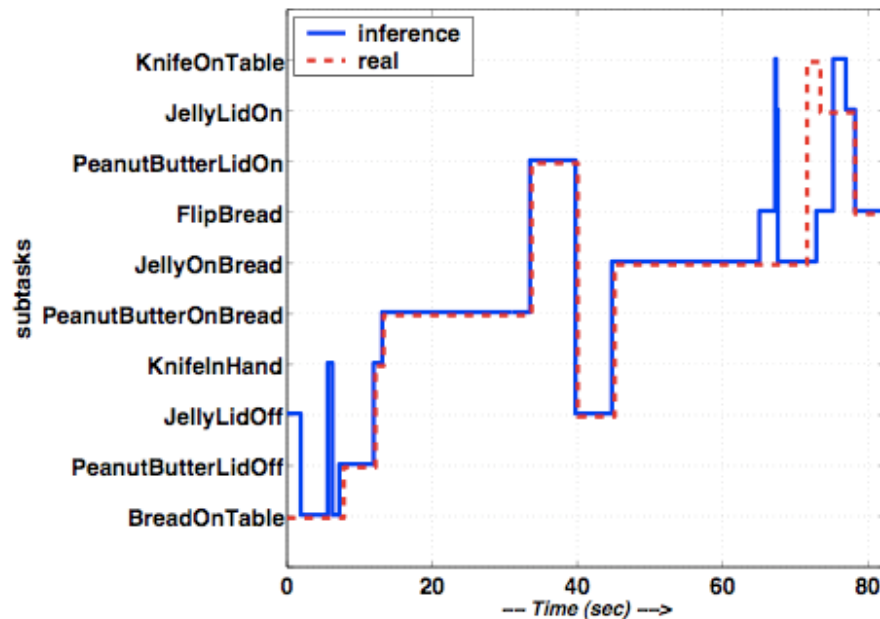
Node Name	# of States	Node Name	# of States
task	80	time frame	20
subtask	10	hand frequency	2
hand object	4	hand reaching	2
gaze object	5	recognized object	5

Yi and Ballard *IJHR* to appear





(a) Offline behavior recognition



Task Classification based on all the data is near perfect

Task Classification based on the data in $(0, t)$ can contain errors