Video-Based Event Detection

Ph.D. research of Somboon Hongeng at the
University of Southern California (2003)

Slides adapted from a talk of S. Hongeng at
Hamburg University in October 2003

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Goals and Motivation

- **Retrieves semantic information from video**
  - Determines if it contains any interesting events
  - When and Where? (i.e., spatial and temporal dimensions)
- **Applications include Video Surveillance, Video Summarization, Human-Machine Interaction, Intelligent Living Spaces**

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Monitoring of Vehicle Behaviors

"go through checkpoint"

- **Checkpoint is the area between the two tanks**

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Monitoring of Activities in a Crowd

- **Multiple actors and objects**
- **Interaction among individual actions**

"theft at phone-booth (PB)"

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Challenges of Event Detection

- **Generic event representation**
- **Effective and robust event recognition**
  - Bridges the gap between pixel values and symbolic event description
  - Computation of uncertainties
    - imperfect tracking of “objects” in noisy videos
    - similar activities must be distinguished
  - Variation in execution styles, temporal durations
  - Generic object recognition
  - Use and acquisition of scene and task context
  - …

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Prior State of the Art

- **Action Recognition using Bayesian networks**
  - Remagnino et al. (1998), Buxton & Gong (1995)
  - Only handles static or simple events
- **Action Recognition using HMMs**
  - Ohya (1992), Starner (1998), Oliver et al. (2000)
  - Parameter space becomes too large in complex events
- **Syntactic Pattern Recognition of Actions**
  - Pinhanez (1998), Ivanov & Bobick (2000)
  - Action units are assumed to be detected and segmented reliably

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Large-Scale Event Detection System

- **Videos taken by a single, calibrated camera**
- **Moving objects are observed from a distance**
  - Closely coordinated movements of body parts cannot be observed reliably
  - Blob shapes and trajectories are main sources of info
- **Scene and task contexts are given**
  - Interesting events to be detected are known and can be modeled a priori
  - Locations and types of scene objects are known

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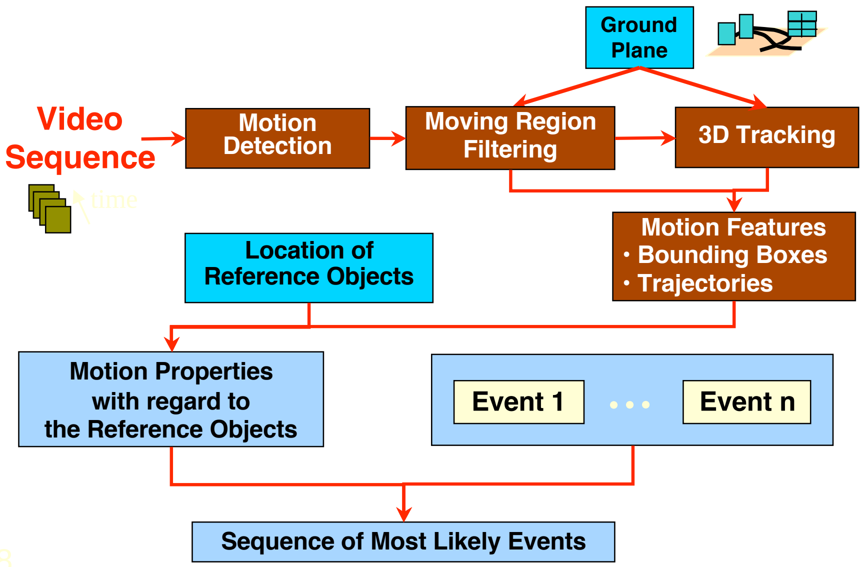
System Overview



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Motion Detection & Tracking

- **Statistical background modeling**
  - Pixel-wise mode computation
- **Detects moving regions by background subtraction**
- **Tracks objects by making correspondence between moving regions at different times**
  - Moving regions may split due to low contrast, noise
  - Uses distance on ground plane to select blob correspondence across timeframes
  - Filters split regions based on color distribution consistency

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Tracking “Theft at PhoneBooth”

- **Ground tracks are noisy in low camera angle**
  - Few pixels mistake projects to several meters

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Event Classification

- **Single Thread Events**
  - Simple Event
    - Short, coherent unit of movement (e.g., “going toward”)
    - Static poses (e.g., “stand”, “crouch”)
  - Composite Events
    - Linearly ordered continuous sequence of events
    - Long-term (normally longer than 30 frames)
- **Multiple Thread Events**
  - Temporal and logical combination of two or more single thread events

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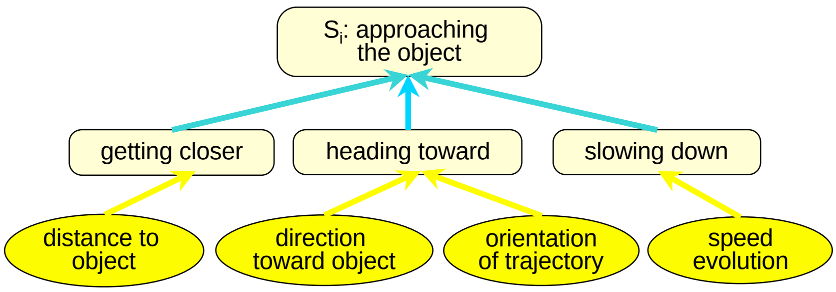
Object Class and Simple Event Modeling



- **Object classes and simple events are modeled by a Bayesian Network of sub-events or properties of shape and trajectory of the actor**
- **Recognized by computing $P(S_{i,t} | O_t)$ at each time frame**

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Inferring $P(S_i|O_t)$

- **Compute "evidence": O_t**
  - Properties related to object trajectories
  - Properties related to bounding boxes
- **Compute $P(S_i|O_t)$ from O_t using Bayes' rule**
  - Assume conditional probabilities are Gaussian
    - Estimate Gaussian parameters from 600 frames of event samples
  - Normalize $P(S_i|O_t)$ based on all alternative events (S_j, S_k, etc…)

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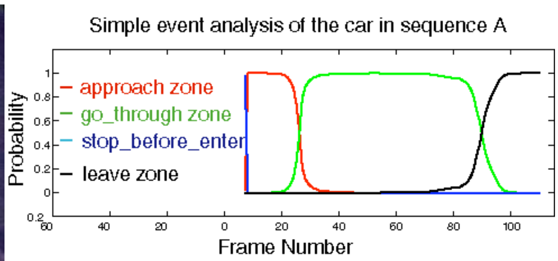
Simple Event Analysis of "Checkpoint A"



- **Evolution of the output of Bayesian networks $P(S_i|O_t)$ of four simple events**
- **The "zone" is shown by the quadrangle**

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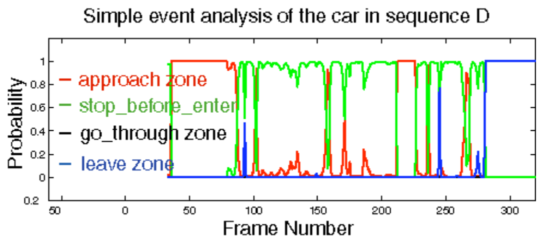
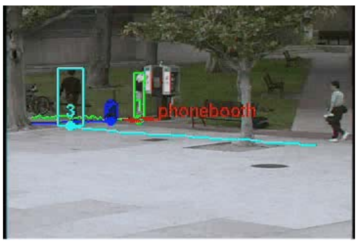
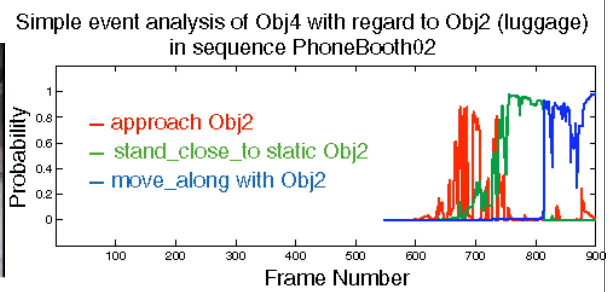
Simple Event Analysis of "Checkpoint D"



- **Evolution of the output of Bayesian networks $P(S_i|O_t)$ of four simple events**

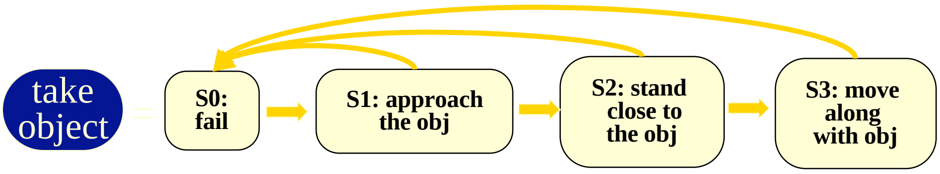
Simple Events of "Take Object"





- **Output of Bayesian networks $P(S_i|O_t)$ of three sub-events of "take object"**

Composite Event Modeling



- **Finite state automaton is used to represent long-term composite events**
- **Dynamics of composite event are modeled by the transitions from one event state to another**
  - Durations of event states can vary
  - Given the Bayesian probabilities of each event state computed for a period of time, a sequence of event states must be segmented appropriately

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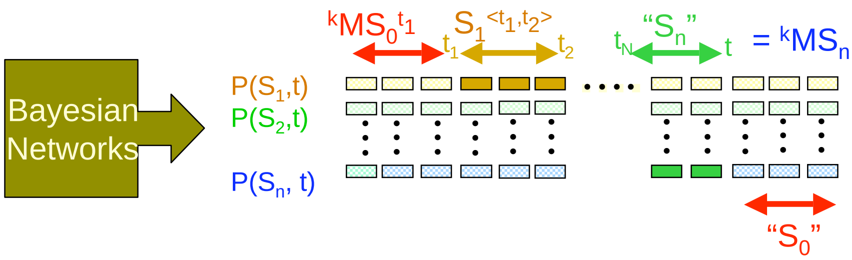
Recognition of Composite Event *k*



- **Let $S_0,\ldots,S_n$ be states of composite event ^kMS; $O=(O_1,\ldots,O_t)$ be the observations; ^kMS_i be the fact that S_i is the current state of ^kMS**
- **^kMS_n is recognized at frame t by computing**

$$P(^kMS_n^t|O)=\alpha_0 \sum_{\forall (t_1,\ldots,t_n)} P(O|\,^kMS_0^{t_1}\, S_1^{<t_1,t_2>} \ldots S_n^{<t_n,t>})\, P(^kMS_n^t)$$

Note: we drop k in the next slides for clarity

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Factoring $P(O|MS_n^t)$ and $P(MS_n^t)$

- **Under semi-HMM assumption that**
  - $O^{<t_m,t_{m+1}>}$ is independent of $S_n^{<t_n,t_{n+i}>}$ given $S_m^{<t_m,t_{m+1}>}$
  - probability of S_m making a transition to S_n depends on the *duration* of S_m ,

  we have:

$$P(MS_n^t|O) = \alpha_0 \sum_{\forall (t_1,\ldots,t_n)} P(MS_0^{t_1})\, P(O^{<1,t_1>}|\, MS_0^{t_1})\; a_{1,0}\, P(d_{s_1}=t_2-t_1)\, P(O^{<t_1,t_2>}|S_1^{<t_1,t_2>}) \ldots a_{n,n-1}\, P(d_{s_n}=t-t_n)\, P(O^{<t_n,t>}|\, S_n^{<t_n,t>})$$

- $a_{n,m}$: the probability of the path from S_m to S_n
- $P(d_{s_m})$: the distribution of event duration of S_m ,
  - estimated using direct method, assuming a Gaussian
  - uniform distributions for highly variable event durations

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Computing $P(MS_n^t|O)$

- **Assuming that O^t and $S_n^{t'}$ are independent given S_n^t , $P(O^{<t_m,t_n>}|S_m^{<t_m,t_n>})$ can be computed from Bayesian probabilities as:**

$$P(O^{<t_m,t_n>}|S_m^{<t_m,t_n>}) = \beta_{<t_m,t_n>} \prod_{t_m <= t <= t_n} P(S_m^t|(O^t)$$

$$\beta_{<t_m,t_n>} = \prod_{t_m <= t <= t_n} \frac{P(O^t)}{P(S_m^t)}$$ **is a normalizing constant**

- **Let** $P'(MS_N^t|O)$ **be the normalized** $P(MS_N^t|O)$**;**

  Bel $(S_i^{<t_i,t_{i+1}>},O^{<t_i,t_{i+1}>})$ **be** $P(d_{s_i}=t_{i+1}-t_i) \prod_{t_i <= t <= t_{i+1}} P(S_i^t|(O^t)$**;**

  We have:

$$P'(MS_N^t|O) = \sum_{\forall (t_1,\ldots,t_N)} P'(MS_0^{t_1}|\, O^{<1,t_1>}) \prod_{1 <= i <= n} a_{i,i-1}\, Bel\, (S_i^{<t_i,t_{i+1}>},O^{<t_i,t_{i+1}>})$$

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Computing $P'(MS_n^t|O)$ Efficiently

- **Direct computation of $P'(MS_n^t|O)$ is $O(nT^n)$**
- **Efficient recursive algorithm based on Dynamic Programming can achieve $O(nT)$**

$$P'(MS_n^t|O) = \sum_{\forall (t_1, \dots, t_n)} P'(MS_0^{t_1}|\, O^{<1,t_1>}) \prod_{1 <= i <= n} a_{i,i-1}\, Bel\, (S_i^{<t_i,t_{i+1}>}, O^{<t_i,t_{i+1}>})$$

$$\Downarrow$$

$$P'(MS_n^t|O) = \sum_{\forall (t_n)} a_{n,n-1}\, Bel\, (S_n^{<t_n,t>}, O^{<t_n,t>})\, P'(MS_{n-1}^{t_n}|\, O^{<1,t_n>})$$

At frame t, for all S_i, update *Bel* $(S_i^{<t_i,t>}, O^{<t_i,t>})$ with Bayesian probability $P(S_i^t|(O^t)$; multiply it with $P'(MS_{i-1}^{t_i}|\, O^{<1,t_i>})$ that is already computed

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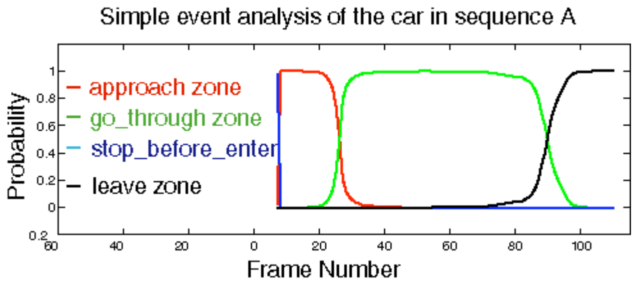
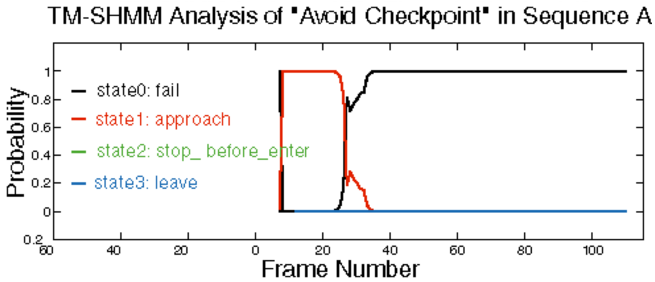
Analysis of "Go Through Checkpoint"

$P(S_i|Ot)$



$P'(MS_i^t|O)$



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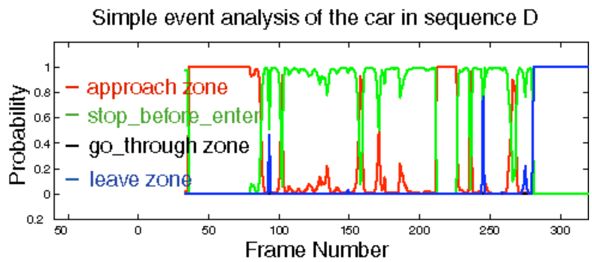
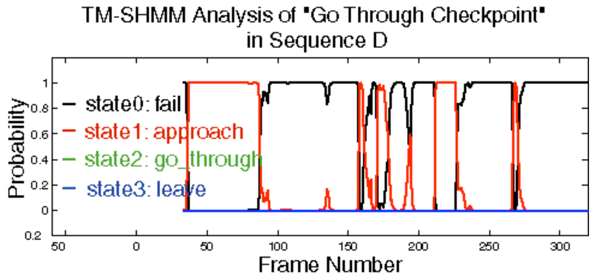
Analysis of “Avoid the Checkpoint”

$P(S_i|Ot)$



$P'(MS_i^t|O)$



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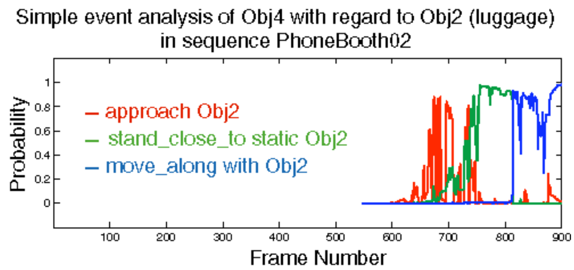
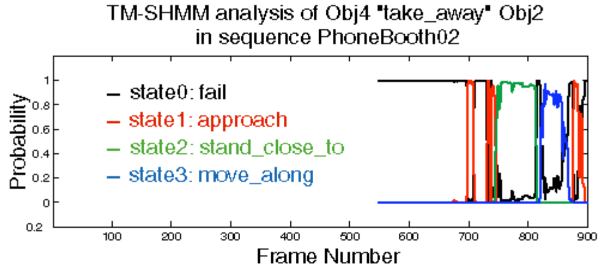
Composite Event: “Take Object”

$P(S_i|Ot)$



$P'(MS_i^t|O)$



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Segmenting Composite Events

- **Set a prob threshold to detect ending times ($^k t^e_1, \dots, {}^k t^e_p$) of event instances 1,..,p of $^k MS_n$**
- **At time frame t, compute $P(MS^*{}_n^t|O)$:**

$$P(MS^*{}_n^t|O) = \alpha_0 \max_{\forall (t_1,\dots,t_n)} P(O|\, MS_0^{t_1}\, S_1^{<t_1,t_2>} \dots S_n^{<t_n,t>})\, P(MS_n^t)$$

  - Backtrack the transitions to t_1 and keep track of q most likely starting times ($^k t^s_1, {}^k t^s_2, \dots, {}^k t^s_q$) during $^k t^e_{i-1}$ and $^k t^e_i$
- **Likelihood of event instance i that ends at $^k t^e_i$ is defined as the maximum value of $P'(MS_n^t|O)$ during ($^k t^e_{i-1}, {}^k t^e_i$)**

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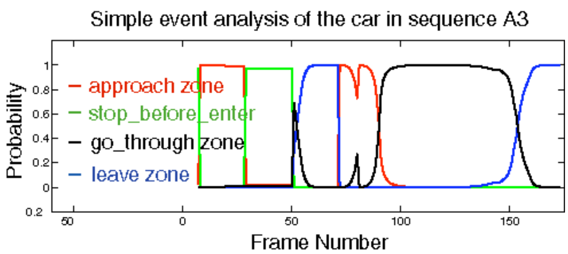
Simulation: Concatenation of "Avoid" and "Go Through"

Sequence A3



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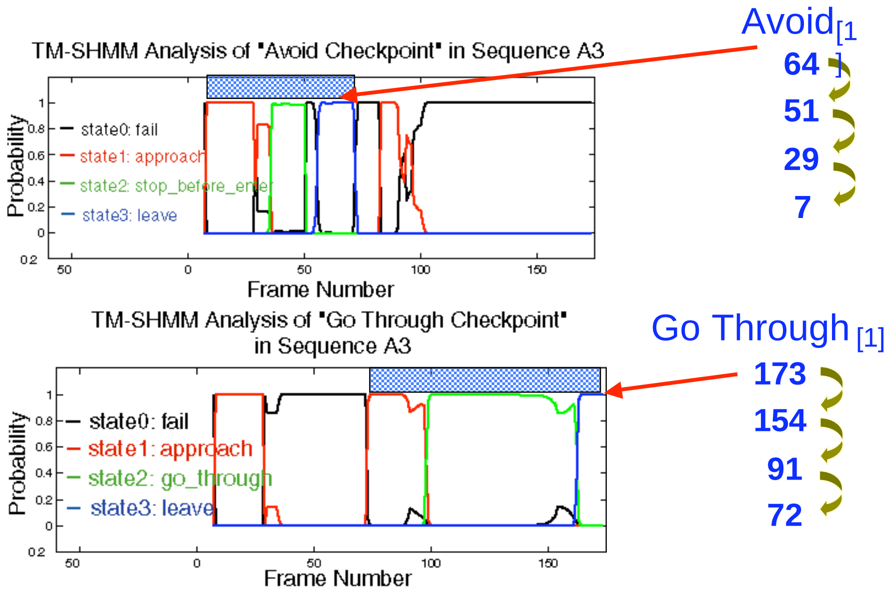
Segmenting “Avoid” and “Go Through”



Multi-Thread Event Modeling

- **Global activities can be described by several actors performing related actions ...**
  - Action threads are related by temporal/logical constraints
  - May overlap in a non-linear fashion
- **... represented by an event graph**
  - Nodes are single-thread events
  - Links indicate temporal relations represented by *Interval-Based Temporal Logic*
    - “starts”, “meets”, “during”, “before”, “overlaps”, …

"Theft at Phone Booth (PB)"

- **Defines five action threads:**
  - Obj1 *bring-in* Obj2
  - Obj1 *use-phone*
  - Obj3 *take* Obj2
  - Obj3 *leave* Obj1
  - Obj2 *taken-away-from* Obj1

- **Defines the appropriate temporal relations**
  - Obj1 *bring-in* Obj2 *starts before* Obj1 *use-phone*
  - Obj3 *take* Obj2 *occurs during* Obj1 *use-phone*
  - …

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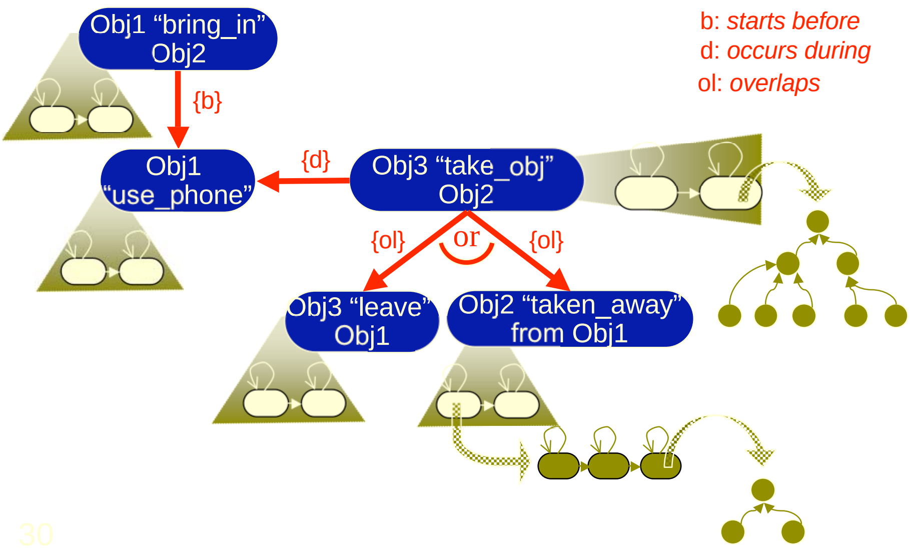
Event Graph for "Theft at PB"



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Multi-Thread Event Recognition

- **Individual event recognition is uncertain**
- **Several instances of events may be detected during a period of time**
  - "approaches", "stops", "approaches"….
- **Search for the event threads that best fit the required *"interval-based relations"***
  - How to evaluate the relations of event instances?

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Evaluation of Temporal and Logical Relations

- ***Temporal Relations* are evaluated by combining the probabilities of event instances subject to the corresponding temporal constraint**
  - P("A *starts before* B") =

    $$\max_{\forall (m,n)} P(A_m)\, P(B_n), \text{ if } \mathit{Start}(A_m) < \mathit{Start}(B_n),$$

    where "m" and "n" indicate instances of events
- ***Logical Relation "Or"* is evaluated by taking the maximum value, i.e.**
  - P("A *or* B") = $\max_{\forall (m,n)} (P(A_m), P(B_n))$

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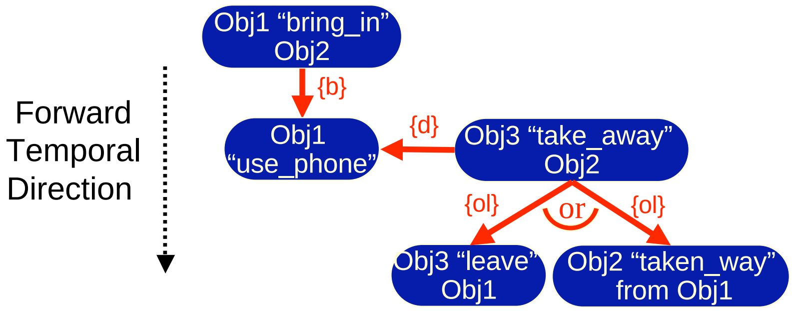
Inference of a Multi-Thread Event



- **Propagate temporal constraints and probabilities of events along forward temporal direction of event graph**
  - We need to consider *“bring_in **before** use_phone”* before we evaluate *“take_away **during** use_phone”*
- **O(TP^{R+1}) complexity if there are R event relations and P average number of event instances with different starting times**

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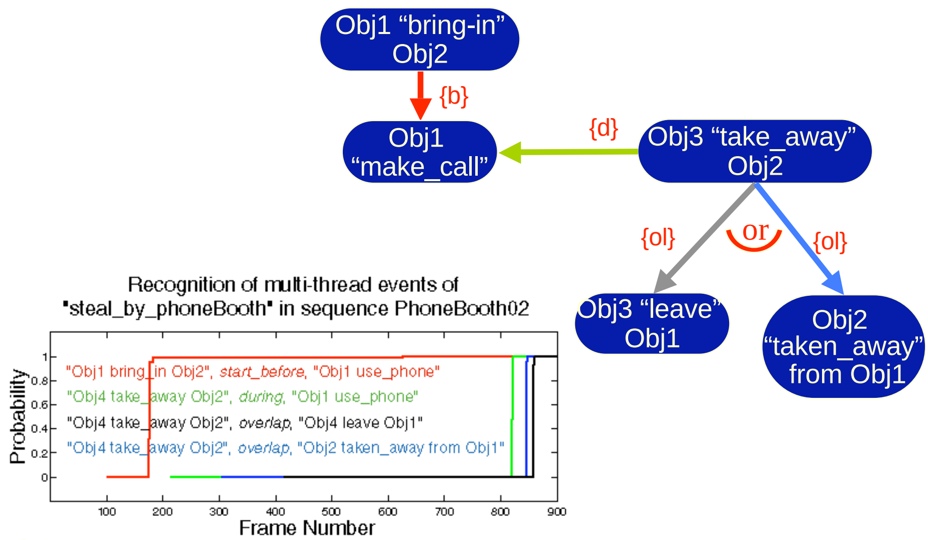
Recognition of “Theft at PB”



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Annotated Videos

- **Needs standard interface for video content descriptions**
  - eXtended Markup Language (XML) interface can be defined for event descriptions
- **Event analysis results can be written in XML**
  - moving object and event descriptions
  - allows the search for content of videos
- **Information in XML files can be parsed and overlaid on the original videos for visualization**

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Annotated “Theft at PB”

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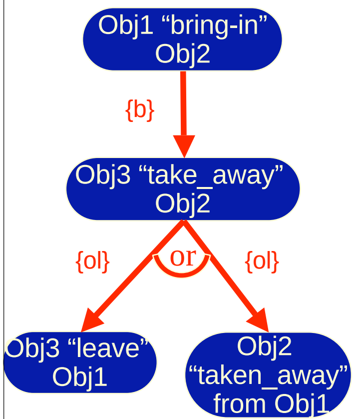
Annotated “Object Transfer”



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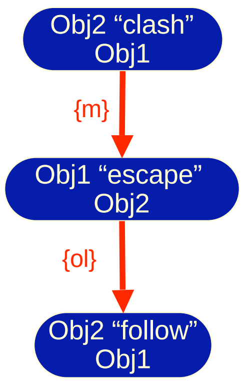
Annotated “Assault”



m: meet
ol: overlap

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Performance

- **96.7% accuracy on discriminating competing single-thread events of 30 objects (including human and vehicles)**
- **Small trajectory perturbation with Gauss noise**
  - Performance drops 5% on 40 simulated noisy sequences corrupted with N(μ=0,σ=6.68cm), equivalent of human walking speed variance
- **Large variations simulating different execution styles (and some tracking blunders)**
  - 81% detection rate, 16% false alarms

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Computation Time

- **P2-333 MHz, 128 MB RAM (approximately 1/8th of today's processing power)**
- **Computation time excludes motion detection and tracking processes**

Sequence	No of objs	Frames	SE/CE/MT/Ctx	Time (sec)	fps
Chekpnt A	2	109	38/3/0/1	2.5	43.6
Chekpnt D	3	292	38/3/0/1	18	16.22
Assault	2	240	68/8/1/0	22.5	10.67
Object Transfer	3	640	83/11/3/1	453	0.71
Steal by Blocking	4	460	104/15/2/3	994	0.46

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Conclusion and Future Work

- **Probabilistic event analysis is robust, but performance depends on tracking accuracy**
- **Closely coordinated actions (e.g. dancing) may require enhancements to the framework**
- **Object recognition remains a difficult problem**
- **A language formalism can be provided for defining events to ease human communication**
- **Needs to extend high level interpretation logic**
- **Extension to multi-camera systems**
- **Integrates with other types of information**
  - Face, gestures, sounds, text, etc.