Hard & Soft Fusion in Defence and Security – Discussion of Examples

1. Tracking-derived Anomaly Detection
2. Extended Objects and Object Clusters
3. Fusion for Security Assistance Systems

NATO LECTURE SERIES STO IST-155

ADVANCED ALGORITHMS FOR EFFECTIVELY FUSING HARD AND SOFT INFORMATION

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What is the methodological essence of *Multiple Source Object Tracking*?

Learn classified tracks of time-varying objects from uncertain data!

Which object properties are of interest?

Define an *object state* at varying time instants.

Which information is to be fused?

Time series of report data, context information

How to describe imprecise information?

E.g. functions of the state: pdfs, PHDs, intensities

What does “learning” from reports mean?

Iteratively calculate these functions (Bayes!)

What is required for the learning process?

Source and evolution models, data association

How to initiate/terminate object tracks?

Sequential decision making (implicitly, explicitly)

Elements for Situation Pictures: Tracks of Time-varying Objects

Which object properties are of interest? $\rightarrow$ ***state*** X_k ***at time*** t_k

- road-moving vehicle: odometer count x_k $\quad X_k = (x_k, \dot{x}_k)$
- position, speed, acceleration: $\quad X_k = (\mathbf{r}_k, \dot{\mathbf{r}}_k, \ddot{\mathbf{r}}_k)$
- joint state of several objects: $\quad X_k = (\mathbf{x}_k^1, \mathbf{x}_k^2, \ldots)$
- attributes, e.g. radar cross section $x_k \in \mathbb{R}^+$: $X_k = (\mathbf{x}_k, x_k)$
- maneuvering phase, object class $i_k \in \mathbb{N}$: $\quad X_k = (\mathbf{x}_k, i_k)$

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The general tracking equations

Prediction

$$p(X_k|Z^{k-1}) = \int dX_{k-1}\, \underbrace{p(X_k|X_{k-1})}_{\text{evolution}}\, \underbrace{p(X_{k-1}|Z^{k-1})}_{\text{filtering } t_{k-1}}$$

filtering

$$p(X_k|Z^k) = \frac{p(Z_k|X_k)\, p(X_k|Z^{k-1})}{\int dX_k\, \underbrace{p(Z_k|X_k)}_{\text{sensor model}}\, \underbrace{p(X_k|Z^{k-1})}_{\text{prediction}}}$$

retrodiction

$$p(X_l|Z^k) = \int dX_{l+1}\, \frac{\overbrace{p(X_{l+1}|X_l)}^{\text{evolution}}\, \overbrace{p(X_l|Z^l)}^{\text{filtering } t_l}}{\underbrace{p(X_{l+1}|Z^l)}_{\text{prediction } t_{l+1}}}\, \underbrace{p(X_{l+1}|Z^k)}_{\text{retrodiction } t_{l+1}}$$

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Anomaly Detection: Part of Situational Awareness

Fusing incomplete and imperfect pieces of complementary sensor and context information to focus human decision makers / decision making systems to events requiring special attention or actions.

Fusion-based anomaly detection is either unobtainable otherwise or exceeds what can be obtained by single sources in accuracy, reliability, or cost.

Here: emphasis on intuitively clear examples; no more general theory on "anomalous behavior".

Key observation in tracking-driven anomaly detection:

The methods of target tracking and data fusion have actually evolved to a mature key technology, but their full potential of of enabling research and development in maritime situational awareness and anomaly detection still waits to be realized.

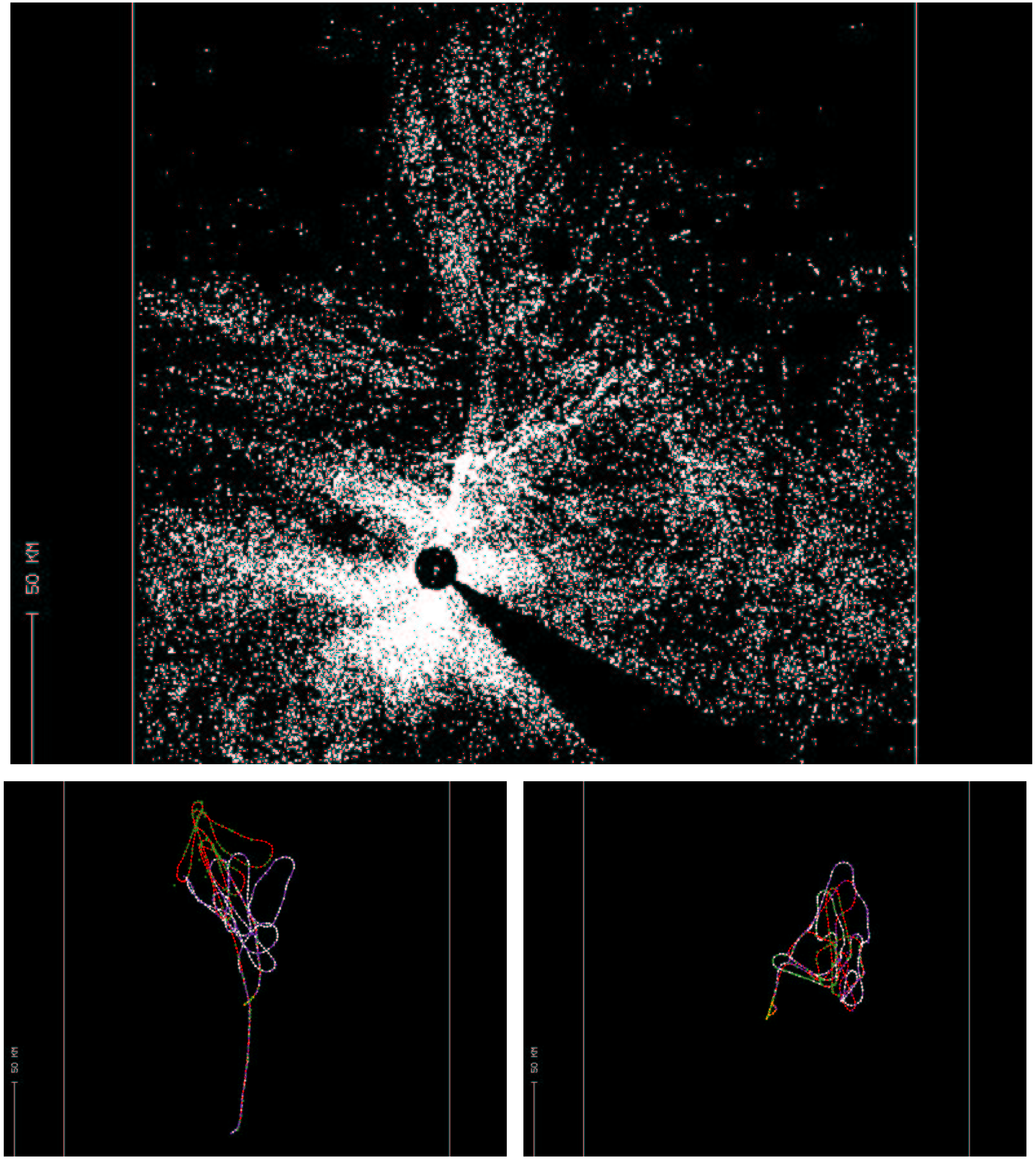
Promising approach to anomaly detection:

Tracking-derived Situation Elements

1. Classification-based detection of anomalies
2. Violation of space-time regularity patterns

Track-based inference of object properties

- **Velocity history:** vehicle, helicopter, plane
- **Acceleration history:** threat: no under-wing weapons
- **Rare events:** truck by night on dirt road near a border
- **Object interrelations:** resulting from formation, convoy
- **Object sources / sinks:** classification by origin / designation
- **Classification:** road-moving vehicle, ‘on-road’ $\rightarrow$ ‘off-road’



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Tracking-derived Situation Elements

1. **Classification-based detection of anomalies**
2. **Violation of space-time regularity patterns**

Using *time invariant* or *slowly changing* knowledge about the overall behavior

Space-time regularity patterns: examples

- sea-/air-lanes as motion constraints
- planning information to be obeyed

Benefit of space-time regularity patterns

- improved the track accuracy/continuity
- pattern violation: 'anomaly' detection

Tracking-based motion pattern extraction

- generation of context knowledge
- fairly precise, timely information

On Integrating Planning Information into Tracking

- space-time waypoints $\mathcal{W}$ to be passed at given times via particular lanes
- tolerances: known error covariance matrices for each waypoint / object
- impact of waypoints if plan is kept: $p(\mathrm{x}_l|\mathcal{W}, \mathcal{Z}^k)$, “artificial sensor data”
- treat sensor data with time stamps before waypoints as “out-of sequence”
- if plan is kept: improved track accuracy / continuity, data association

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Sequential Anomaly Detection: Pattern Violation

h_1: The observed objects obey an underlying pattern.
h_0: The pattern is not obeyed (e.g. off-lane, unplanned).

characterized by $P(\text{accept } h_1|h_1)$, $P(\text{accept } h_1|h_0)$.

Consider the ratio: $$\frac{p(h_1|Z^k)}{p(h_0|Z^k)} = \underbrace{\frac{p(Z^k|h_1)}{p(Z^k|h_0)}}_{=:\text{LR}(k)} \frac{p(h_1)}{p(h_0)}.$$

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Calculate $\mathrm{LR}(k)$ iteratively using evolution / sensor models:

$$\mathrm{LR}(k) = \frac{\int d\mathbf{x}_k \overbrace{p(Z_k, m_k|\mathbf{x}_k)}^{\text{likelihood}} \overbrace{p(\mathbf{x}_k|Z^{k-1}, h_1)}^{\text{prediction}}}{\int d\mathbf{x}_k \, p(Z_k, m_k|\mathbf{x}_k) \underbrace{p(\mathbf{x}_k|Z^{k-1}, h_0)}_{\text{no pattern assumed}}} \mathrm{LR}(k-1).$$

Restart: re-confirm “normality” or to detect a violation at last.

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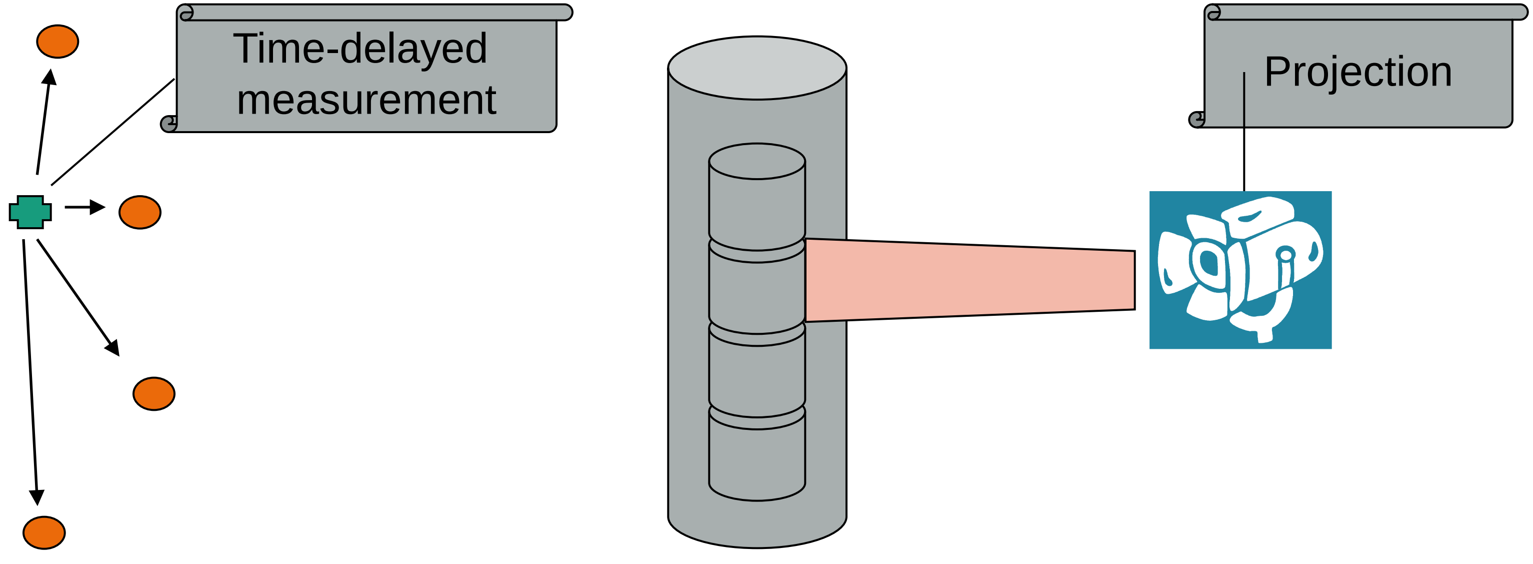
Accumulated state densities (ASD)



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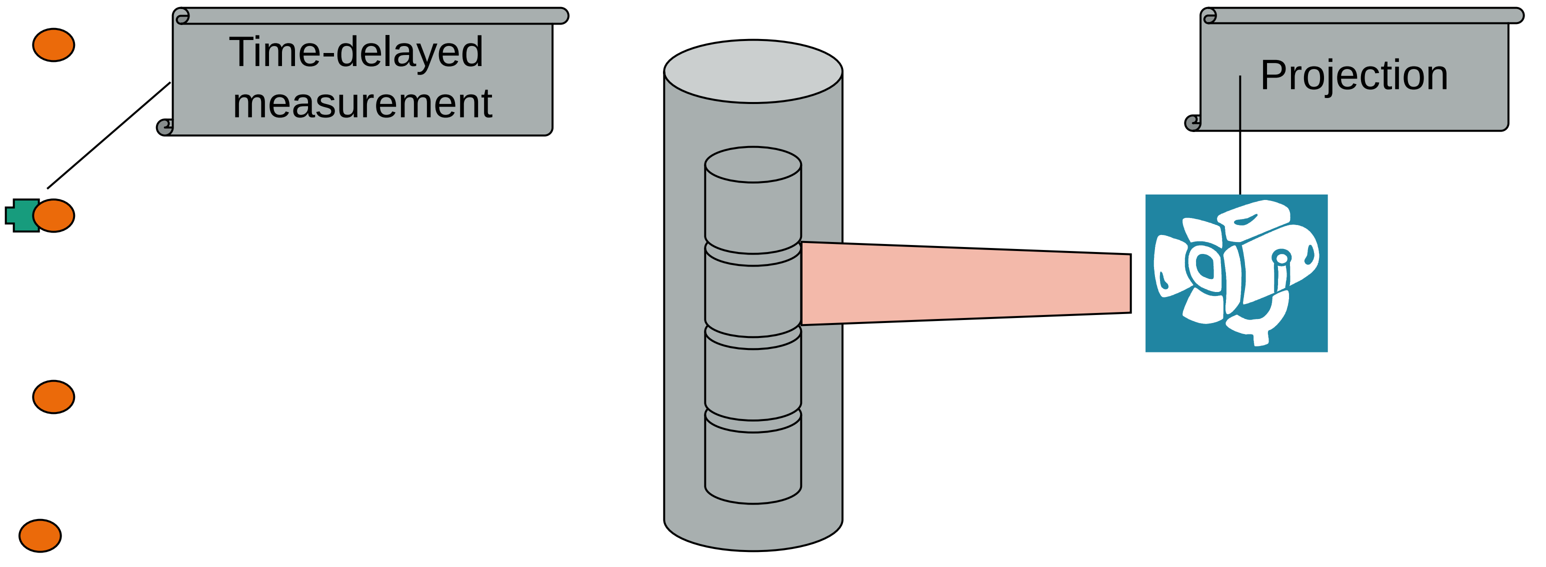
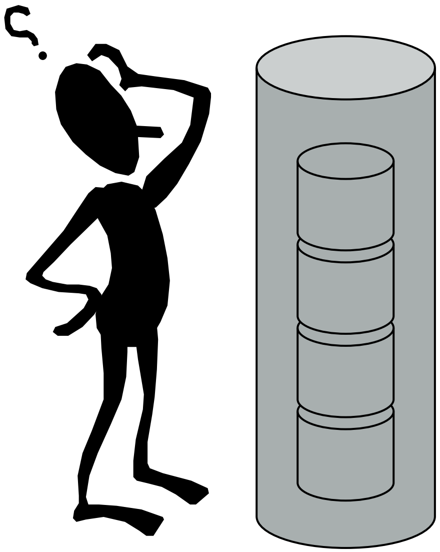


ASD – A Joint PDF



In order to calculate the posterior of the joint pdf

$$\boxed{p(\mathbf{x}_k, \ldots, \mathbf{x}_n | Z^k)}$$

we define the ASD state as

$$\boxed{\mathbf{x}_{k:n} = (\mathbf{x}_k, \ldots, \mathbf{x}_n)}$$

Goal: find a recursive formulation. Let's see ..

$$\boxed{p(\mathbf{x}_{k:n}|Z^k) = \frac{p(\mathbf{z}_k|\mathbf{x}_{k:n})\, p(\mathbf{x}_{k:n}|Z^{k-1})}{\int \mathrm{d}\mathbf{x}_{k:n}\, p(\mathbf{z}_k|\mathbf{x}_{k:n})\, p(\mathbf{x}_{k:n}|Z^{k-1})}}$$

Elementary Operations

Elementary operations on this product lead to

$$\boxed{\begin{aligned}
p(\mathbf{x}_{k:n}|Z^k) &= \prod_{l=n}^{k} \mathcal{N}\big(\mathbf{\Pi}_l \mathbf{x}_{k:n};\, \mathbf{\Pi}_l \mathbf{x}_{k:n|k},\, \mathbf{U}_{l|k}\big) \\
&\propto \prod_{l=n}^{k} \mathrm{e}^{-\frac{1}{2}\left(\mathbf{\Pi}_l \mathbf{x}_{k:n} - \mathbf{\Pi}_l \mathbf{x}_{k:n|k}\right)^\top \mathbf{U}_{l|k}^{-1}\left(\mathbf{\Pi}_l \mathbf{x}_{k:n} - \mathbf{\Pi}_l \mathbf{x}_{k:n|k}\right)} \\
&= \mathrm{e}^{-\frac{1}{2}\left(\mathbf{x}_{k:n} - \mathbf{x}_{k:n|k}\right)^\top \left(\sum_{l=n}^{k} \mathbf{\Pi}_l^\top \mathbf{U}_{l|k}^{-1} \mathbf{\Pi}_l\right)\left(\mathbf{x}_{k:n} - \mathbf{x}_{k:n|k}\right)} \\
&= \mathcal{N}\big(\mathbf{x}_{k:n};\, \mathbf{x}_{k:n|k},\, \mathbf{P}_{k:n|k}\big)
\end{aligned}}$$

with an ASD covariance matrix

$$\boxed{\mathbf{P}_{k:n|k} = \Big(\sum_{l=n}^{k} \mathbf{\Pi}_l^\top \mathbf{U}_{l|k}^{-1} \mathbf{\Pi}_l\Big)^{-1}.}$$

Elementary Operations

Elementary operations on this product lead to

$$\boxed{\begin{aligned} p(\mathbf{x}_{k:n}|Z^k) &= \prod_{l=n}^{k} \mathcal{N}\big(\mathbf{\Pi}_l \mathbf{x}_{k:n};\, \mathbf{\Pi}_l \mathbf{x}_{k:n|k},\, \mathbf{U}_{l|k}\big) \\ &\propto \prod_{l=n}^{k} \mathrm{e}^{-\frac{1}{2}\left(\mathbf{\Pi}_l \mathbf{x}_{k:n} - \mathbf{\Pi}_l \mathbf{x}_{k:n|k}\right)^\top \mathbf{U}_{l|k}^{-1}\left(\mathbf{\Pi}_l \mathbf{x}_{k:n} - \mathbf{\Pi}_l \mathbf{x}_{k:n|k}\right)} \\ &= \mathrm{e}^{-\frac{1}{2}\left(\mathbf{x}_{k:n} - \mathbf{x}_{k:n|k}\right)^\top \left(\sum_{l=n}^{k} \mathbf{\Pi}_l^\top \mathbf{U}_{l|k}^{-1} \mathbf{\Pi}_l\right)\left(\mathbf{x}_{k:n} - \mathbf{x}_{k:n|k}\right)} \\ &= \mathcal{N}\big(\mathbf{x}_{k:n};\, \mathbf{x}_{k:n|k},\, \mathbf{P}_{k:n|k}\big) \end{aligned}}$$

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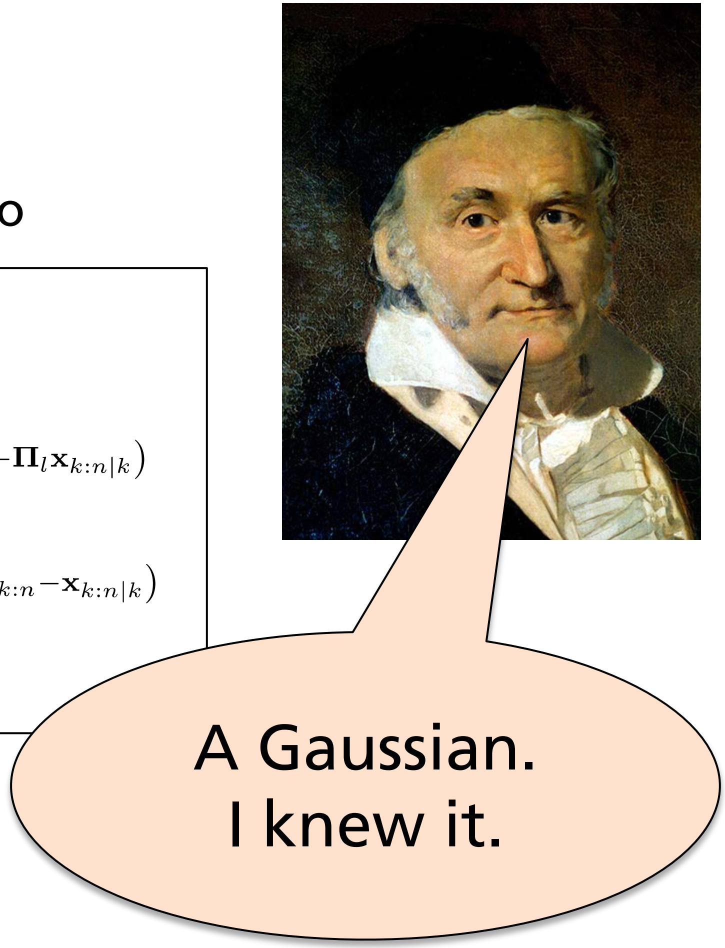

The Inverse ASD Covariance Matrix

Summing up yields the inverse covariance matrix:

$$\boxed{\begin{array}{l}\mathbf{P}_{k:n|k}^{-1} = \\ \begin{pmatrix} \mathbf{T}_{k|k} & -\mathbf{W}_{k-1|k}^{\top}\mathbf{U}_{k-1|k}^{-1} & \mathbf{O} & \cdots & \mathbf{O} \\ -\mathbf{U}_{k-1|k}^{-1}\mathbf{W}_{k-1|k} & \mathbf{T}_{k-1|k} & -\mathbf{W}_{k-2|k}^{\top}\mathbf{U}_{k-2|k}^{-1} & \ddots & \vdots \\ \mathbf{O} & -\mathbf{U}_{k-2|k}^{-1}\mathbf{W}_{k-2|k} & \ddots & \ddots & \mathbf{O} \\ \vdots & \ddots & \ddots & \mathbf{T}_{n+1|k} & -\mathbf{W}_{n|k}^{\top}\mathbf{U}_{n|k} \\ \mathbf{O} & \cdots & \mathbf{O} & -\mathbf{U}_{n|k}\mathbf{W}_{n|k} & \mathbf{T}_{n|k} \end{pmatrix}\end{array}}$$

where

$$\boxed{\mathbf{T}_{l|k} = \begin{cases} \mathbf{P}_{k|k}^{-1} + \mathbf{W}_{l-1|l}^{\top}\mathbf{U}_{l-1|k}^{-1}\mathbf{W}_{l-1|l} & \text{for } l = k \\ \mathbf{U}_{l|k}^{-1} + \mathbf{W}_{l-1|l}^{\top}\mathbf{U}_{l-1|k}^{-1}\mathbf{W}_{l-1|l} & \text{for } n < l < k \\ \mathbf{U}_{n|k}^{-1} & \text{for } l = n \end{cases}.}$$

Are we done now?

Not yet – we "only" have to invert this accumulated information matrix.

ASD Covariance Matrix

Elementary matrix operations yield

$$
\mathbf{P}_{k:n|k} =
\begin{pmatrix}
\mathbf{P}_{k|k} & \mathbf{P}_{k|k}\mathbf{W}^{\top}_{k-1|k} & \mathbf{P}_{k|k}\mathbf{W}^{\top}_{k-2|k} & \cdots & \mathbf{P}_{k|k}\mathbf{W}^{\top}_{n|k} \\
\mathbf{W}_{k-1|k}\mathbf{P}_{k|k} & \mathbf{P}_{k-1|k} & \mathbf{P}_{k-1|k}\mathbf{W}^{\top}_{k-2|k-1} & * & \mathbf{P}_{k-1|k}\mathbf{W}^{\top}_{n|k-1} \\
\mathbf{W}_{k-2|k}\mathbf{P}_{k|k} & \mathbf{W}_{k-2|k-1}\mathbf{P}_{k-1|k} & \mathbf{P}_{k-2|k} & * & \vdots \\
\vdots & * & * & * & \mathbf{P}_{n+1|k}\mathbf{W}^{\top}_{n|n+1} \\
\mathbf{W}_{n|k}\mathbf{P}_{k|k} & \mathbf{W}_{n|k-1}\mathbf{P}_{k-1|k} & \cdots & \mathbf{W}_{n|n+1}\mathbf{P}_{n+1|k} & \mathbf{P}_{n|k}
\end{pmatrix}
$$

where

$$
\mathbf{W}_{l|k} = \prod_{\lambda=l}^{k-1} \mathbf{W}_{\lambda|\lambda+1}
$$

What are the Parameters?

The updated track state is given by

$$\boxed{\begin{aligned}\mathbf{x}_{k:m:n|k,m} &= \mathbf{x}_{k:m:n|k} + \mathbf{W}_{k:m:n}(\mathbf{z}_m - \mathbf{H}_m\mathbf{\Pi}_m\mathbf{x}_{k:m:n|k})\\ \mathbf{P}_{k:m:n|k,m} &= \mathbf{P}_{k:m:n|k} - \mathbf{W}_{k:m:n}\mathbf{S}_{k:m:n}\mathbf{W}_{k:m:n}^\top,\end{aligned}}$$

where

$$\boxed{\begin{aligned}\mathbf{S}_{k:m:n} &= \mathbf{H}_m\mathbf{\Pi}_m\mathbf{P}_{k:m:n|k}\mathbf{\Pi}_m^\top\mathbf{H}_m^\top + \mathbf{R}_m\\ \mathbf{W}_{k:m:n} &= \mathbf{P}_{k:m:n|k}\mathbf{\Pi}_m^\top\mathbf{H}_m^\top\mathbf{S}_{k:m:n}^{-1}.\end{aligned}}$$

That is the updated state. Finally.

Rudolph E. Kalman

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modeling: sensor data produced by extended objects

- actual measurement errors of individual scattering centers unimportant
- the ‘message’ of individual plots is dominated by the object extension
- individual plots to be interpreted as measurements of the object center
- related ‘measurement error’ proportional to extension *to be estimated*

Elements for Situation Pictures: Tracks of Time-varying Objects

Which object properties are of interest? $\rightarrow$ *state* X_k *at time* t_k

- road-moving vehicle: odometer count x_k $\quad X_k = (x_k, \dot{x}_k)$
- position, speed, acceleration: $\quad X_k = (\mathbf{r}_k, \dot{\mathbf{r}}_k, \ddot{\mathbf{r}}_k)$
- joint state of several objects: $\quad X_k = (\mathbf{x}_k^1, \mathbf{x}_k^2, \dots)$
- attributes, e.g. radar cross section $x_k \in \mathbb{R}^+$: $X_k = (\mathbf{x}_k, x_k)$
- maneuvering phase, object class $i_k \in \mathbb{N}$: $\quad X_k = (\mathbf{x}_k, i_k)$
- object shape: SPD random matrices $\mathbf{X}_k$ $\quad X_k = (\mathbf{x}_k, \mathbf{X}_k)$

extended objects: simplified description

- **kinematical state** at time t_k: x_k = (position, velocity, ...)
- **object extension** at time t_k: approximately by an ellipse
- **size:** volume, **shape:** ratio of semi-axes, spatial **orientation**
- extension: **SPD matrix** X_k (Symmetric, Positively Definite)

augmented state: kinematical state *vector* x_k, extension *matrix* X_k

Generalize BAYESian tracking to extended objects.

n_k plots $Z_k = \{\mathbf{z}_k^j\}_{j=1}^{n_k}$ at time t_k, accumulated data $\mathcal{Z}^k = \{Z_k, n_k, \mathcal{Z}^{k-1}\}$

The conditional pdf $p(\mathrm{x}_k, \mathrm{X}_k|\mathcal{Z}^k)$ describes what is known about the extended object state $\mathrm{x}_k, \mathrm{X}_k$ based on all sensor data up to time t_k.

'extended object tracking': *iterative* calculation of $p(\mathrm{x}_k, \mathrm{X}_k|\mathcal{Z}^k)$.

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- $p(\mathrm{x}_k, \mathrm{X}_k|\mathcal{Z}^k) = p(\mathrm{x}_k|\mathrm{X}_k, \mathcal{Z}^k)\, p(\mathrm{X}_k|\mathcal{Z}^k)$ **extended object 'track'**
- $p(Z_k, n_k|\mathrm{x}_k, \mathrm{X}_k)$ **sensor output to be processed, i.e. the likelihood**
- $p(\mathrm{x}_k|\mathcal{Z}^k) = \int d\mathrm{X}_k\, p(\mathrm{x}_k, \mathrm{X}_k|\mathcal{Z}^k)$ **kinematics of the extended object**

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Generalize BAYESian tracking to extended objects.

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- $p(\mathbf{x}_k, \mathbf{X}_k|\mathcal{Z}^k) = p(\mathbf{x}_k|\mathbf{X}_k, \mathcal{Z}^k)\, p(\mathbf{X}_k|\mathcal{Z}^k)$ **extended object 'track'**

  $p(\mathbf{x}_k|\mathbf{X}_k, \mathcal{Z}^k)$: **assume Gaussian density**

  $p(\mathbf{X}_k|\mathcal{Z}^k)$: **assume inverse Wishart density**

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measurement eq.: $\mathbf{z}_k^j = (h_k^1\mathbf{I}_d, h_k^2\mathbf{I}_d, h_k^3\mathbf{I}_d)\mathbf{x}_k + \mathbf{u}_k, \quad \mathbf{u}_k \sim \mathcal{N}(\mathbf{o}, \mathbf{R}_k)$

$$= (\mathbf{H}_k \otimes \mathbf{I}_d)\mathbf{x}_k + \mathbf{u}_k$$

simple example: $\mathrm{H}_k = (1, 0, 0)$ **(position measurement)**

measurement error: $\mathbf{R}_k \propto \mathbf{X}_k$ ***unknown!***

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Excursus: Properties of Kronecker products (1/3)

The Kronecker product $\mathrm{A} \otimes \mathrm{B}$ of two matrices

$\mathrm{A} = (a_{ij})_{i=1,j=1}^{m,n}$, B **is defined by:**

$$\mathbf{A} \otimes \mathrm{B} = \begin{pmatrix} a_{11}\mathrm{B} & a_{12}\mathrm{B} & \cdots & a_{1n}\mathrm{B} \\ a_{21}\mathrm{B} & a_{22}\mathrm{B} & \cdots & a_{2n}\mathrm{B} \\ \vdots & \vdots & & \vdots \\ a_{m1}\mathrm{B} & a_{m2}\mathrm{B} & \cdots & a_{mn}\mathrm{B} \end{pmatrix}.$$

Excursus: Properties of Kronecker products (2/3)

For matrices A, B, C and a scalar α:

$$
\begin{aligned}
(\mathbf{A} \otimes \mathbf{B}) \otimes \mathbf{C} &= \mathbf{A} \otimes (\mathbf{B} \otimes \mathbf{C}) \\
\alpha \otimes \mathbf{A} &= \alpha \mathbf{A} = \mathbf{A} \alpha = \mathbf{A} \otimes \alpha \\
(\mathbf{A} \otimes \mathbf{B})(\mathbf{C} \otimes \mathbf{D}) &= \mathbf{AC} \otimes \mathbf{BD} \\
(\mathbf{A} \otimes \mathbf{B})^\top &= \mathbf{A}^\top \otimes \mathbf{B}^\top \\
(\mathbf{A} \otimes \mathbf{B})^{-1} &= \mathbf{A}^{-1} \otimes \mathbf{B}^{-1}.
\end{aligned}
$$

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Excursus: Properties of Kronecker products (3/3)

For quadratic matrices A, B we obtain:

$$\mathrm{tr}[\mathbf{A} \otimes \mathbf{B}] = (\mathrm{tr}\mathbf{A})\,(\mathrm{tr}\mathbf{B}).$$

The determinant of $\mathrm{A} \otimes \mathrm{B}$ is given by the determinants of A, B

with $m = \mathrm{dim}(\mathbf{A})$, $n = \mathrm{dim}(\mathbf{B})$:

$$|\mathbf{A} \otimes \mathbf{B}| = |\mathbf{A}|^n |\mathbf{B}|^m.$$

modeling: 'collective' kinematics of extended objects

kinematics: $\mathbf{x}_k = \left(\mathbf{r}_k^\top, \dot{\mathbf{r}}_k^\top, \ddot{\mathbf{r}}_k^\top\right)^\top, \quad d = \dim(\mathbf{r}_k),\ \dim(\mathbf{X}_k) = d \times d$

temporal evolution: $\mathbf{x}_k = \mathbf{\Phi}_{k|k-1}\mathbf{x}_{k-1} + \mathbf{v}_k, \quad \mathbf{v}_k \sim \mathcal{N}(\mathbf{o}, \mathbf{\Delta}_{k|k-1})$

evolution matrix: $\Phi_{k|k-1} = \begin{pmatrix} \mathbf{I}_d & \Delta t_k \mathbf{I}_d & \frac{1}{2}\Delta t_k^2 \mathbf{I}_d \\ \mathbf{O}_d & \mathbf{I}_d & \Delta t_k \mathbf{I}_d \\ \mathbf{O}_d & \mathbf{O}_d & \mathrm{e}^{-\Delta t_k/\theta}\mathbf{I}_d \end{pmatrix} = \mathbf{F}_{k|k-1} \otimes \mathbf{I}_d$

plant noise: $\boxed{\mathbf{\Delta}_{k|k-1} = \mathbf{D}_{k|k-1} \otimes \mathbf{X}_k}$ **important assumption!**

plant noise covariance $\mathrm{D}_{k|k-1} \otimes \mathrm{X}_k$: discussion of its structure

- ***formal argument:***
  - assuming this structure, there exists a mutually *conjugate pair* of pdfs $p(\mathrm{x}_k, \mathbf{X}_k|\mathcal{Z}^{k-1})$ and $p(Z_k, n_k|\mathrm{x}_k, \mathbf{X}_k)$; i.e. $p(\mathrm{x}_k, \mathbf{X}_k|\mathcal{Z}^k)$ belongs to the same family as $p(\mathrm{x}_k, \mathbf{X}_k|\mathcal{Z}^{k-1}) \Rightarrow$ analytical update equations!

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- ***practical arguments:***
  - Trajectories of group targets are the predictable, i.e. the inertial, the smaller their extension: ‘maneuvering becomes dangerous’.
  - The larger a formation/convoy, the more probable are ‘split-off’ maneuvers; ‘large’ prediction covariances take this into account.
  - Large target groups/object swarms produce so many measurements that the prediction step becomes unimportant compared to filtering.

prediction: kinematical state, object extension matrix

$$\boxed{p(\mathbf{x}_k, \mathbf{X}_k|\mathcal{Z}^{k-1}) = \underbrace{p(\mathbf{x}_k|\mathbf{X}_k, \mathcal{Z}^{k-1})}_{\textbf{\textit{vector} variate}} \underbrace{p(\mathbf{X}_k|\mathcal{Z}^{k-1})}_{\textbf{\textit{matrix} variate}}}$$

track structure at time t_{k-1} $\quad p(\mathbf{x}_{k-1}|\mathbf{X}_k, \mathcal{Z}^{k-1}) = \mathcal{N}\big(\mathbf{x}_{k-1};\, \mathbf{x}_{k-1|k-1},\, \mathbf{P}_{k-1|k-1} \otimes \mathbf{X}_k\big)$

is preserved after prediction to t_k: $\quad p(\mathbf{x}_k|\mathbf{X}_k, \mathcal{Z}^{k-1}) = \mathcal{N}\big(\mathbf{x}_k;\, \mathbf{x}_{k|k-1},\, \mathbf{P}_{k|k-1} \otimes \mathbf{X}_k\big)$

with: $\mathbf{x}_{k|k-1} = (\mathbf{F}_{k|k-1} \otimes \mathbf{I}_d)\mathbf{x}_{k-1|k-1}, \quad \mathbf{P}_{k|k-1} = \mathbf{F}_{k|k-1}\mathbf{P}_{k-1|k-1}\mathbf{F}_{k|k-1}^\top + \mathbf{D}_{k|k-1}$ **KALMAN type prediction**

prediction: kinematical state, object extension matrix

$$p(\mathbf{x}_k, \mathbf{X}_k | \mathcal{Z}^{k-1}) = \underbrace{p(\mathbf{x}_k | \mathbf{X}_k, \mathcal{Z}^{k-1})}_{\textit{vector}\text{ variate}} \underbrace{p(\mathbf{X}_k | \mathcal{Z}^{k-1})}_{\textit{matrix}\text{ variate}}$$

track structure at time t_{k-1} $\quad p(\mathbf{x}_{k-1} | \mathbf{X}_k, \mathcal{Z}^{k-1}) = \mathcal{N}\big(\mathbf{x}_{k-1}; \mathbf{x}_{k-1|k-1}, \mathbf{P}_{k-1|k-1} \otimes \mathbf{X}_k\big)$

is preserved after prediction to t_k: $\quad p(\mathbf{x}_k | \mathbf{X}_k, \mathcal{Z}^{k-1}) = \mathcal{N}\big(\mathbf{x}_k; \mathbf{x}_{k|k-1}, \mathbf{P}_{k|k-1} \otimes \mathbf{X}_k\big)$

with: $\mathbf{x}_{k|k-1} = (\mathbf{F}_{k|k-1} \otimes \mathbf{I}_d)\mathbf{x}_{k-1|k-1}$, $\quad \mathbf{P}_{k|k-1} = \mathbf{F}_{k|k-1}\mathbf{P}_{k-1|k-1}\mathbf{F}^{\top}_{k|k-1} + \mathbf{D}_{k|k-1}$ $\quad$ **KALMAN type prediction**

Assume for $p(\mathbf{X}_k|\mathcal{Z}^{k-1})$ and $p(\mathbf{X}_k|\mathcal{Z}^{k})$ *inverse* WISHART densities:

$$p(\mathbf{X}_k|\mathcal{Z}^{k-1}) = \mathcal{IW}\big(\mathbf{X}_k; \nu_{k|k-1}, \mathbf{X}_{k|k-1}\big) \propto |\mathbf{X}_k|^{-\frac{\nu_{k|k-1}+d+1}{2}} \operatorname{etr}\big[-\tfrac{1}{2}\mathbf{X}_{k|k-1}\mathbf{X}_k^{-1}\big].$$

$$\mathbb{E}[\mathbf{X}_k] = \frac{\mathbf{X}_{k|k-1}}{\nu_{k|k-1}-d-1}, \quad \operatorname{etr}[\mathbf{A}] = \exp[\operatorname{tr}\mathbf{A}], \ |\mathbf{A}| = \det \mathbf{A}$$

Calculate $\nu_{k|k-1}$, $\mathbf{X}_{k|k-1}$ from $\nu_{k-1|k-1}$, $\mathbf{X}_{k-1|k-1}$ (i.e. the filtering)!

structure of the measurement likelihood function

in general: $p(Z_k, n_k|\mathbf{x}_k, \mathbf{X}_k, \mathcal{Z}^{k-1}) = p(Z_k|n_k, \mathbf{x}_k, \mathbf{X}_k)\, p(n_k|\mathbf{x}_k, \mathbf{X}_k)$

at present: no false returns, unresolved measurements are allowed.

$$\begin{aligned} p(Z_k|n_k, \mathbf{x}_k, \mathbf{X}_k) &= \prod_{j=1}^{n_k} \mathcal{N}\Big(\mathbf{z}_k^j;\ (\mathbf{H}_k \otimes \mathbf{I}_d)\mathbf{x}_k,\ \mathbf{X}_k\Big) \quad \text{(independent plots)} \\ &\propto \mathcal{N}\Big(\mathbf{z}_k;\ (\mathbf{H}_k \otimes \mathbf{I}_d)\mathbf{x}_k,\ \tfrac{1}{n_k}\mathbf{X}_k\Big)\ \mathcal{LW}\Big(\mathbf{Z}_k;\ n_k - 1,\ \mathbf{X}_k\Big) \end{aligned}$$

$$\mathbf{z}_k = \frac{1}{n_k}\sum_{j=1}^{n_k} \mathbf{z}_k^j, \quad \mathbf{Z}_k = \sum_{j=1}^{n_k} (\mathbf{z}_k^j - \mathbf{z}_k)(\mathbf{z}_k^j - \mathbf{z}_k)^\top$$

$$\mathcal{LW}\big(\mathbf{Z}_k;\ n_k - 1,\ \mathbf{X}_k\big) = |\mathbf{X}_k|^{-\frac{n_k-1}{2}}\ \mathrm{etr}\big[-\tfrac{1}{2}\mathbf{Z}_k\mathbf{X}_k^{-1}\big]$$

structure of joint state pdf after the filtering step

exploiting BAYES: $p(Z_k|n_k, \mathbf{x}_k, \mathbf{X}_k)\, p(\mathbf{x}_k, \mathbf{X}_k|\mathcal{Z}^{k-1}) \propto \underbrace{\mathcal{N}\big(\mathbf{x}_k;\, \mathbf{x}_{k|k},\, \mathbf{P}_{k|k} \otimes \mathbf{X}_k\big)}_{\text{KALMAN type update}}$

$$\times \underbrace{|\mathbf{X}_k|^{-\frac{1}{2}}\ \mathrm{etr}\big[-\tfrac{1}{2}\mathbf{N}_{k|k-1}\mathbf{X}_k^{-1}\big]}_{\text{innovation factor}}\ \underbrace{\mathcal{LW}\big(\mathbf{Z}_k;\, n_k - 1,\, \mathbf{X}_k\big)}_{\text{from measurement likelihood}}\ \underbrace{\mathcal{IW}\big(\mathbf{X}_k;\, \nu_{k|k-1},\, \mathbf{X}_{k|k-1}\big)}_{\text{extension prediction}}$$

up to a factor independent of $\mathbf{x}_k$, $\mathbf{X}_k$ with *innovation matrix* $\mathbf{N}_{k|k-1}$ and innov. cov. $S_{k|k-1}$:

$$\boxed{\mathbf{N}_{k|k-1} = S_{k|k-1}^{-1}\big(\mathbf{z}_k - (\mathbf{H}_k \otimes \mathbf{I}_d)\mathbf{x}_{k|k-1}\big)\big(\mathbf{z}_k - (\mathbf{H}_k \otimes \mathbf{I}_d)\mathbf{x}_{k|k-1}\big)^\top}$$

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structure of joint state pdf after the filtering step

exploiting BAYES: $p(Z_k|n_k, \mathbf{x}_k, \mathbf{X}_k)\, p(\mathbf{x}_k, \mathbf{X}_k|\mathbf{Z}^{k-1}) \propto \underbrace{\mathcal{N}\big(\mathbf{x}_k;\, \mathbf{x}_{k|k},\, \mathbf{P}_{k|k} \otimes \mathbf{X}_k\big)}_{\text{KALMAN type update}}$

$$\times \underbrace{|\mathbf{X}_k|^{-\frac{1}{2}}\, \mathrm{etr}\big[-\tfrac{1}{2}\mathbf{N}_{k|k-1}\mathbf{X}_k^{-1}\big]}_{\text{innovation factor}}\; \underbrace{\mathcal{LW}\big(\mathbf{Z}_k;\, n_k - 1,\, \mathbf{X}_k\big)}_{\text{from measurement likelihood}}\; \underbrace{\mathcal{IW}\big(\mathbf{X}_k;\, \nu_{k|k-1},\, \mathbf{X}_{k|k-1}\big)}_{\text{extension prediction}}$$

up to a factor independent of $\mathbf{x}_k$, $\mathbf{X}_k$ with *innovation matrix* $\mathbf{N}_{k|k-1}$ and innov. cov. $S_{k|k-1}$:

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finally: $p(Z_k|n_k, \mathbf{x}_k, \mathbf{X}_k)\, p(\mathbf{x}_k, \mathbf{X}_k|\mathcal{Z}^{k-1}) \propto \underbrace{\mathcal{N}\big(\mathbf{x}_k;\, \mathbf{x}_{k|k},\, \mathbf{P}_{k|k} \otimes \mathbf{X}_k\big)}_{\text{KALMAN type update}}\; \underbrace{\mathcal{IW}\big(\mathbf{X}_k;\, \nu_{k|k},\, \mathbf{X}_{k|k}\big)}_{\text{extension update}}$

with simple update equations: $\mathbf{X}_{k|k} = \mathbf{X}_{k|k-1} + \mathbf{N}_{k|k-1} + \mathbf{Z}_k, \quad \nu_{k|k} = \nu_{k|k-1} + n_k.$

remark: due to the innovation matrix $\mathbf{N}_{k|k-1}$ also in case of point targets the estimation of an unknown measurement error is possible or the 'extension' of an unresolved target group.

marginalization of the joint density $p(\mathrm{x}_k, \mathrm{X}_k | \mathcal{Z}^k)$

sometimes: interest in estimates of the kinematical state x_k only

$$
\begin{aligned}
p(\mathbf{x}_k | \mathcal{Z}_k) &= \int d\mathbf{X}_k \, p(\mathbf{x}_k, \mathbf{X}_k | \mathcal{Z}^k) \\
&= \int d\mathbf{X}_k \, \mathcal{N}\Big(\mathbf{x}_k;\, \mathbf{x}_{k|k},\, \mathbf{P}_{k|k} \otimes \mathbf{X}_k\Big)\, \mathcal{IW}\Big(\mathbf{X}_k;\, \nu_{k|k},\, \mathbf{X}_{k|k}\Big)
\end{aligned}
$$

marginalization of the joint density $p(\mathrm{x}_k, \mathrm{X}_k|\mathcal{Z}^k)$

sometimes: interest in estimates of the kinematical state x_k only

$$\begin{aligned} p(\mathbf{x}_k|\mathcal{Z}_k) &= \textstyle\int d\mathbf{X}_k\, p(\mathbf{x}_k, \mathbf{X}_k|\mathcal{Z}^k) \\ &= \textstyle\int d\mathbf{X}_k\ \mathcal{N}\Big(\mathbf{x}_k;\ \mathbf{x}_{k|k},\ \mathbf{P}_{k|k} \otimes \mathbf{X}_k\Big)\ \mathcal{IW}\Big(\mathbf{X}_k;\ \nu_{k|k},\ \mathbf{X}_{k|k}\Big) \\ &= \mathcal{T}\Big(\mathbf{x}_k;\ \nu_{k|k} + s(1-d),\ \mathbf{x}_{k|k}, \mathbf{P}_{k|k} \otimes \mathbf{X}_{k|k}\Big) \quad \textbf{(standard algebra!)} \end{aligned}$$

multivariate Student-t-density with $\nu_{k|k}$ degrees of freedom

basis for kinematical state estimates with related error covariance matrices,

calculation of expectation gates, extended object track-to-track correlation/fusion, ...

Hard & Soft Fusion in Defence and Security – Discussion of Examples

1. Tracking-derived Anomaly Detection
2. Extended Objects and Object Clusters
3. Fusion for Security Assistance Systems

NATO LECTURE SERIES STO IST-155

ADVANCED ALGORITHMS FOR EFFECTIVELY FUSING HARD AND SOFT INFORMATION

Wolfgang Koch

Priv.-Doz. Dr. rer. nat., FIEEE

Fraunhofer FKIE, Wachtberg

Fraunhofer FKIE

How can "security" be provided?

A parallel: insurance industry ↔ security "industry"

"Security" by mitigating financial risks of individuals by *contributions by many*:

→ statistics, informatics

Insurance industry is a highly important economic factor.

Insurance law: highly developed field of law with significant societal and economic impact.

"Security": mitigating risks by threat recognition from *uncertain information*:

→ statistics, informatics

Public security: growth market BMWi study: 15 B€ in 2016

Emerging security law: supervise Security technology on behalf of liberality and individual rights

On the Notion of "Public Security"

Public Security. The notion of P. S. comprises the integrity of the … fundamental institutions … of the state as well as the integrity of health, honor, freedom, property, and related objects of legal protection of its citizens. Defense against endangerments of P. S. is the task of public security authorities.

Rechtswörterbuch. Hrsg.: C. Creifelds, K. Weber, C.-H. Beck, 2007

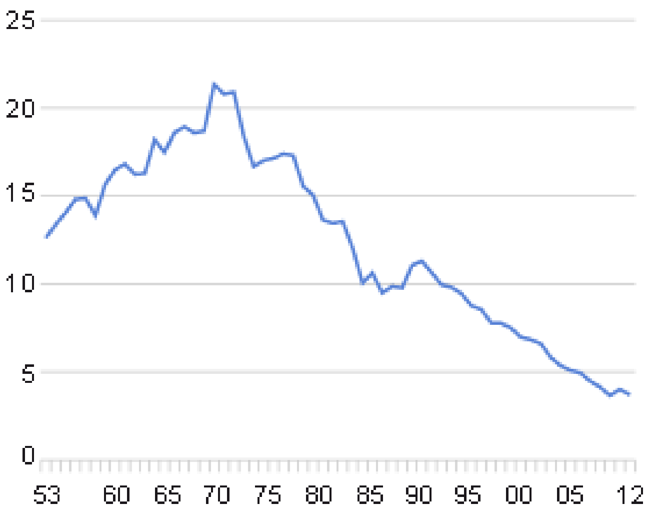
Danger defense for P. S.: profound transformations

- **Omnipresence of networks of surveillance sensors**
- **Algorithms of sensor data fusion: „Cognitive Tools"**

High-quality information from streams of uncertain data!

Excursus: “Physical Integrity” of the Citizens

Traffic Deaths: Germany [thousand]



Obviously effective!

traffic deaths 2012: 28,000 (EU), 1,2 Mio. (global)

Actually, the state should forbid cars.

But: mobility is a desirable good.

- **Technology: inspection, robust car body, belts, airbags, …**
- **Law: traffic regulations, obligatory belts, no phones, …**
- **Insurance: damages may exceed individual fortunes**

Analogously for risk technologies (nuclear plants)

Excursus: “Physical Integrity” of the Citizens

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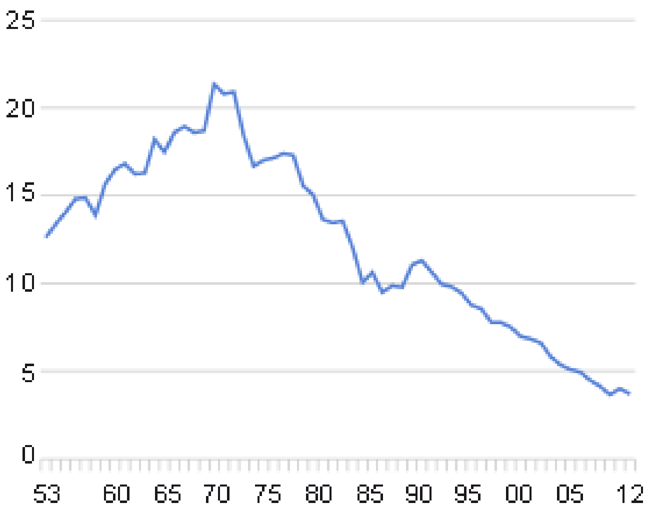

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Analogously for risk technologies (nuclear plants)

11. 09. 2001, USA:	2,976 †
11. 03. 2004, Madrid:	191 †
07. 07. 2005, London:	56 †

Governmental duty:
Prevent terror attacks!

Liberality, privacy, … are (highly!) desired goods.

Why not similarly unexcited actions (technology, laws, insurance, …)?

Example: Hazardous Material in Public Infrastructures

- rare events, large damage
- many persons involved
- complex surveillance task

Responsibility with human beings
New profession: security personnel

Security Assistance Systems:

Focus attention!

- Mitigate operator fatigue
- Constant quality standards
- Exploit new information sources
- Space for human expertise

Security Assistance Systems: Basic Elements

- Disburden from routine and mass tasks → room for human expertise
- Assistance: focus attention to potential threats, hazards.

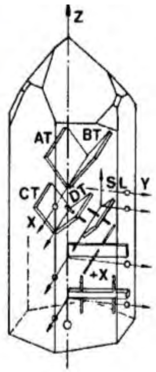
- Permanent operation without disturbing or annoying public life.
- Informational self-determination, privacy: threat-relevant data only.

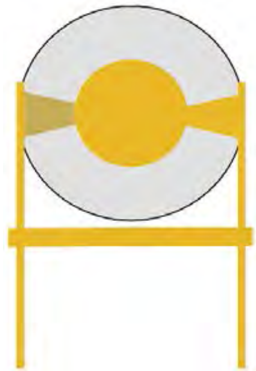
- Exploit “artificial sense organs” (sensors) for detecting anomalies.
- An informatics topic: “fuse” sensor data and context information.
  - Sensor technology, communications, data bases, processing power
  - intelligent exploitation algorithms, interface to human decision makers

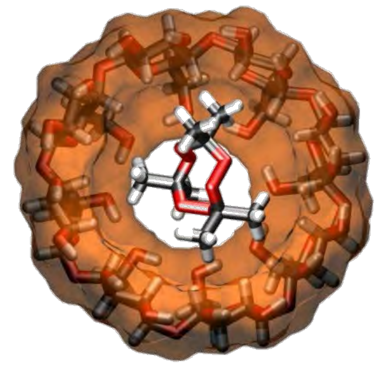
- Combine the strengths of automated and human data exploitation.
  - real-time analysis of vast sensor data streams with constant quality
  - high decision competence in individual situations, expert knowledge

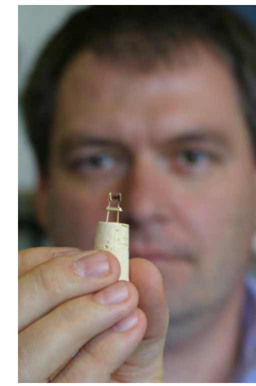
Which Classes of Sensors may be Considered?

ONE Example: Quartz Micro-Balances (QMB) as “artificial noses“

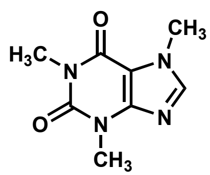




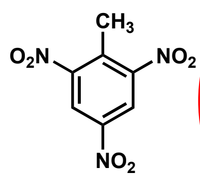




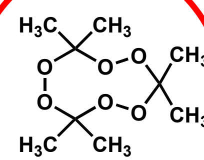
Prof. Dr. S. Waldvogel
Kekulé Institute for
Organic Chemistry
and Biochemistry



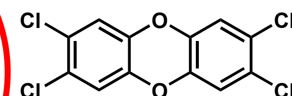
caffeine



TNT



TATP



TCDD

„Home-made explosive“: triacetone triperoxide: measure frequency differences.

Interdisziplinary project: Fraunhofer FKIE, Bonn University (Chemistry, Informatics IV):
Low-cost Hazardous Material Sensors based on Quartz Micro-Balances

Which Classes of Sensors may be Considered?

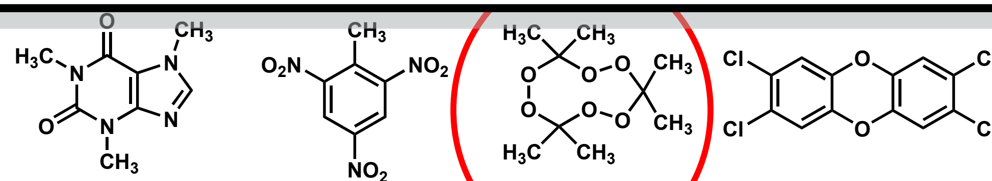
ONE Example: Quartz Micro-Balances (QMB) as "artificial noses"

A fundamental problem: space-time resolution!

How to associate hazardous material signatures to an individual, a good?

relevant also for bio / radioactivity sensors (CBRNE)

Prof. Dr. S. Waldvogel
Kekulé Institute for Organic Chemistry and Biochemistry



caffeine TNT TATP TCDD

„Home-made explosive": triacetone triperoxide: measure frequency differences.

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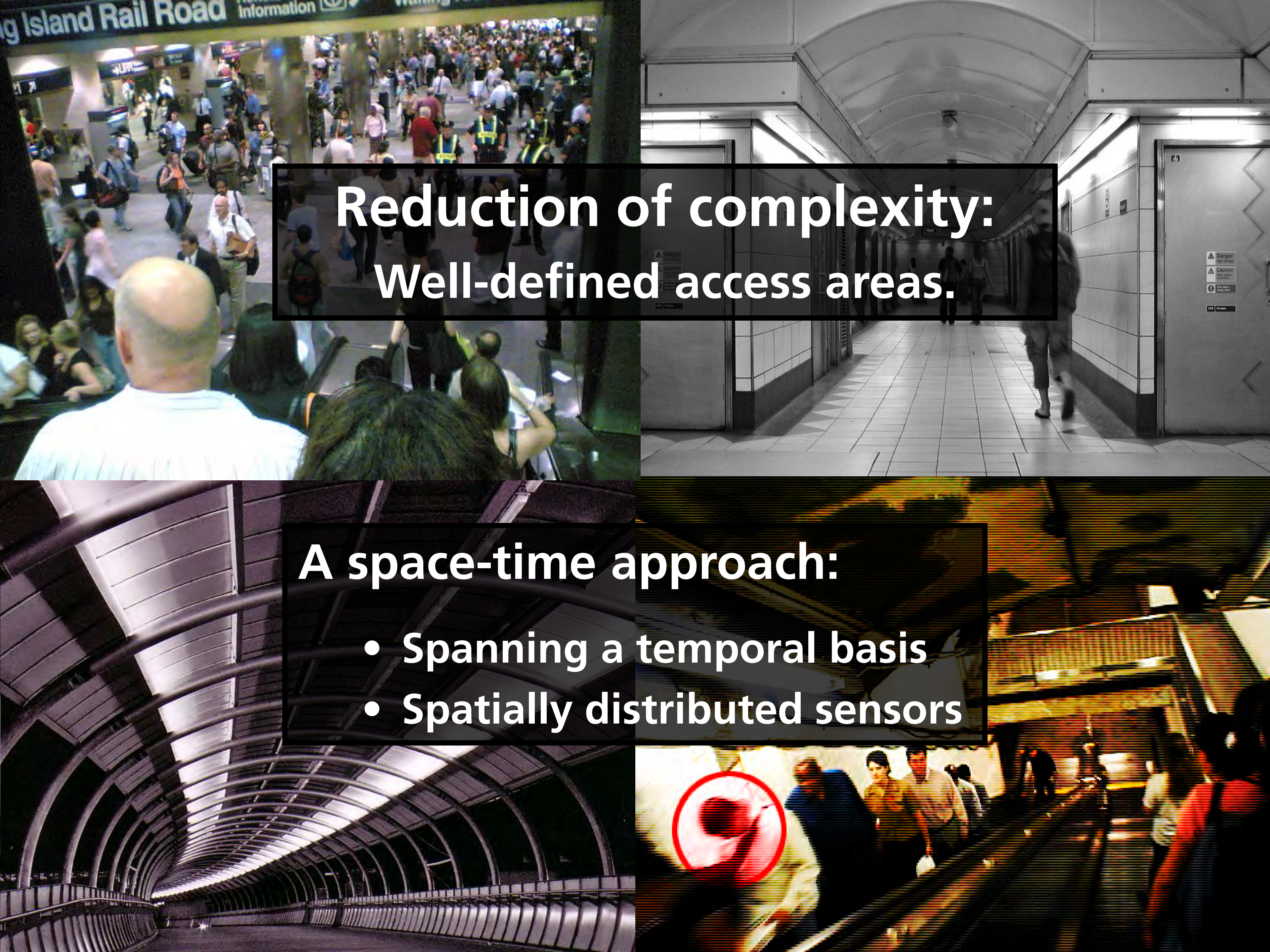
Fraunhofer FKIE



Reduction of complexity:

Well-defined access areas.

A space-time approach:

- Spanning a temporal basis
- Spatially distributed sensors

Security Applications: Well-defined Access Regions.

Task: Detect persons carrying hazardous materials in a person flow.

Escalators / Stairways

Tunnels / Underground

Problem: limited spatio-temporal resolution of chemical sensors

Solution: compensate poor resolution by space-time data fusion

Track Extraction / Maintenance	Video Data	Attributes
Laser-Range-Scanner Sensors	Supporting Information	Chemical Sensors

EU Project HAMLeT: Hazardous Material Localization and Person Tracking

Fraunhofer FKIE

What is the methodological essence of *Multiple Source Object Tracking*?

Learn classified tracks of time-varying objects from uncertain data!

Which object properties are of interest?

Define an *object state* at varying time instants.

Which information is to be fused?

Time series of report data, context information

How to describe imprecise information?

E.g. functions of the state: pdfs, PHDs, intensities

What does "learning" from reports mean?

Iteratively calculate these functions (Bayes!)

What is required for the learning process?

Source and evolution models, data association

How to initiate/terminate object tracks?

Sequential decision making (implicitly, explicitly)

Data Augmentation Methods: Basic Idea

wanted: statements about a quantity $\mathcal{X}$ provided measurements $\mathcal{Z}$ are given.

known: all available knowledge about $\mathcal{X}$ is represented by the pdf $p(\mathcal{X}|\mathcal{Z})$.

problem: the calculation of the probability density $p(\mathcal{X}|\mathcal{Z})$ can be rather difficult.

observation: $p(\mathcal{X}|\mathcal{A}, \mathcal{Z})$ assuming additional information $\mathcal{A}$ may be available.

trick: use the augmented pdf $p(\mathcal{X}|\mathcal{A}, \mathcal{Z})$ to calculate characteristics of $p(\mathcal{X}|\mathcal{Z})$.

EM algorithm : a practical realization of the concept.

iterative localization of a *posterior mode*

Expectation

$\mathcal{X}^l$, $\mathcal{P}^l$ current estimate related to $p(\mathcal{X}|\mathcal{Z})$; initialization!

$$\mathcal{Q}(\mathcal{X}; \mathcal{X}^l, \mathcal{P}^l) = \int_{\text{dom}\mathcal{A}} d\mathcal{A} \log[p(\mathcal{X}|\mathcal{A}, \mathcal{Z})] p(\mathcal{A}|\mathcal{X}^l, \mathcal{P}^l, \mathcal{Z})$$

Maximization

$$\mathcal{X}^{l+1} = \text{argmax}_{\mathcal{X}} \mathcal{Q}(\mathcal{X}; \mathcal{X}^l, \mathcal{P}^l), \quad p(\mathcal{X}^{l+1}|\mathcal{Z}) > p(\mathcal{X}^l|\mathcal{Z})$$

iterate until $|\mathcal{Q}(\mathcal{X}^{l+1}; \mathcal{X}^l, \mathcal{P}^l) - \mathcal{Q}(\mathcal{X}^l; \mathcal{X}^l, \mathcal{P}^l)| < \epsilon$

Extended Target Tracking Filter

Bayesian Extended Target Filter using Random Matrices [Koch 2008]

Application of the Bayesian Formalism yields:

$$p\left(\mathbf{x}_t, \mathbf{X}_t \middle| \mathcal{Z}^t\right) = p\left(\mathbf{x}_t \middle| \mathbf{X}_t, \mathcal{Z}^t\right) p\left(\mathbf{X}_t \middle| \mathcal{Z}^t\right)$$

$$= \mathcal{N}\left(\mathbf{x}_t; \mathbf{x}_{t|t}, \mathbf{P}_{t|t} \otimes \mathbf{X}_t\right) \mathcal{IW}\left(\mathbf{X}_t; \zeta_{t|t}, \mathbf{X}_{t|t}\right)$$

Kinematics (Vector)

Extent (Matrix)

Separate Discussion

Iterative Update Scheme for the Joint State of a **Single Target**

$$\underbrace{p\left(\mathbf{x}_{t-1}, \mathbf{X}_{t-1} \middle| \mathcal{Z}^{t-1}\right)}_{\text{Posterior Density}} \xrightarrow[\text{Model}]{\text{Evolution}} \underbrace{p\left(\mathbf{x}_t, \mathbf{X}_t \middle| \mathcal{Z}^{t-1}\right)}_{\text{Prior Density}} \xrightarrow[\text{Sensor Model}]{\text{Data: } Z_t,\, N_t} \underbrace{p\left(\mathbf{x}_t, \mathbf{X}_t \middle| \mathcal{Z}^t\right)}_{\text{Posterior Density}}$$

Prediction **Filtering**

Closure Property of Wishart + Inverted Wishart Densities under Multiplication ⇨ Principle of Conjugate Priors

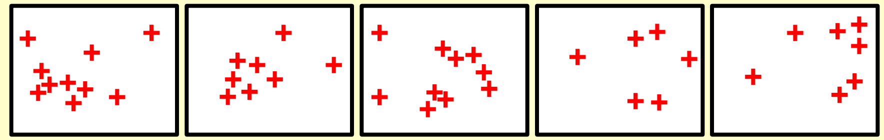
PMHT for Extended Objects: EM Modeling [Wieneke, Koch 2012]

Multiple Extended Target Tracking as Maximization Problem

Given: Sequence of Measurements comprising Noise and Target Data

$$\mathcal{Z} = \left[Z_t\right]_{t=1}^{T}$$

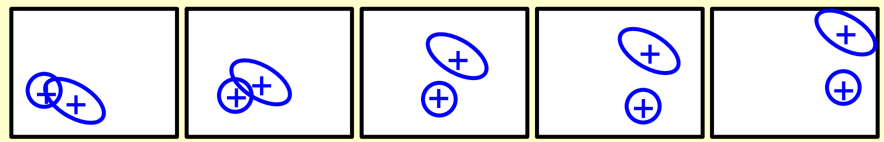
$Z_t \equiv$ Data at scan t



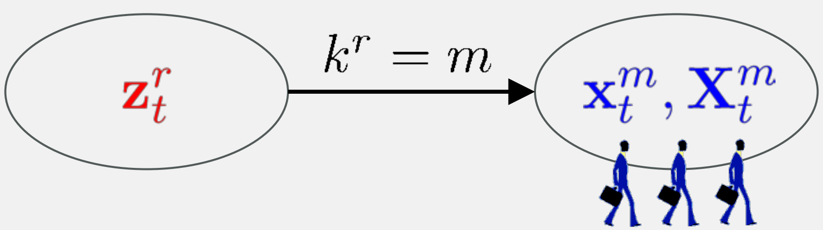
Wanted: Sequences of **Joint Target States** (kinematics, extents)

$$\mathcal{X} = \left[X_t\right]_{t=1}^{T}$$

$$X_t = \left[\mathbf{x}_t^m, \mathbf{X}_t^m\right]_{m=1}^{M}$$



Unknown: Assignments



Problem to solve:

$$\arg\max_{\mathcal{X}} \; p\left(\mathcal{X} \middle| \mathcal{Z}\right)$$

Apply: Expectation-Maximization (EM)

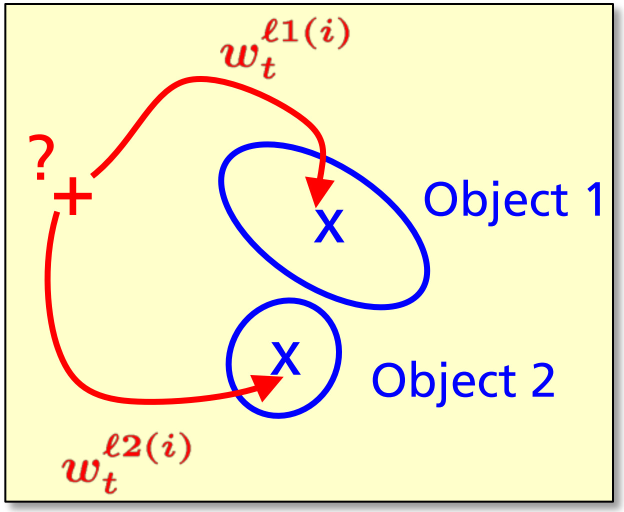
Fraunhofer FKIE

PMHT for Extended Targets: Assignments

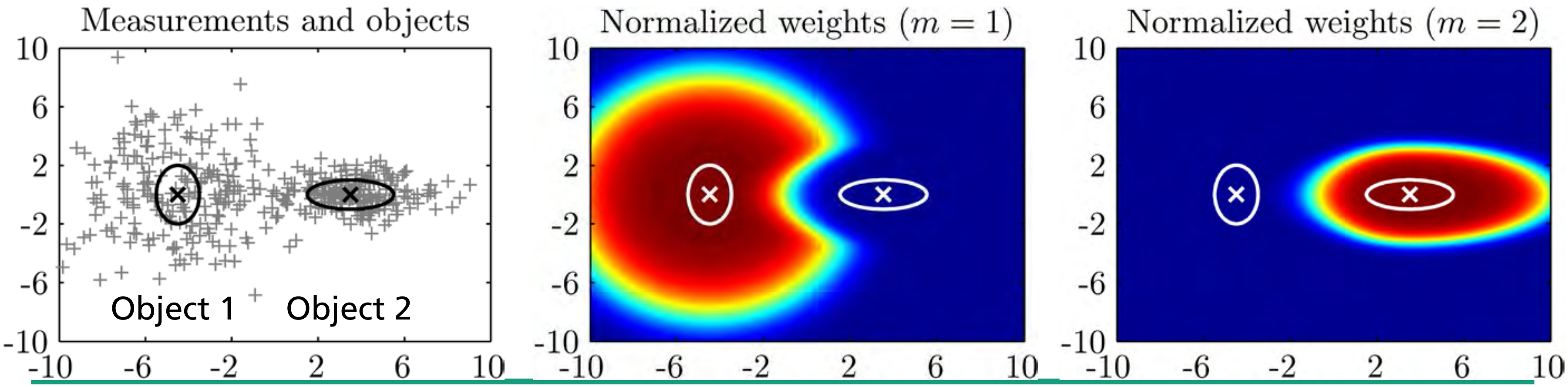
E-Step: Compute Assignment Probabilities

$$w_t^{rm(i)} = \frac{\pi_t^{m(i)} \mathcal{N}\left(\mathbf{z}_t^r; \mathbf{H}\mathbf{x}_t^{m(i)}, \mathbf{X}_t^{m(i)} + \mathbf{R}\right)}{\sum\limits_{m'=0}^{M} \pi_t^{m'(i)} \mathcal{N}\left(\mathbf{z}_t^r; \mathbf{H}\mathbf{x}_t^{m'(i)}, \mathbf{X}_t^{m(i)} + \mathbf{R}\right)}$$

Dependent on Extent Estimate



Example with two Gaussian-Shaped Objects

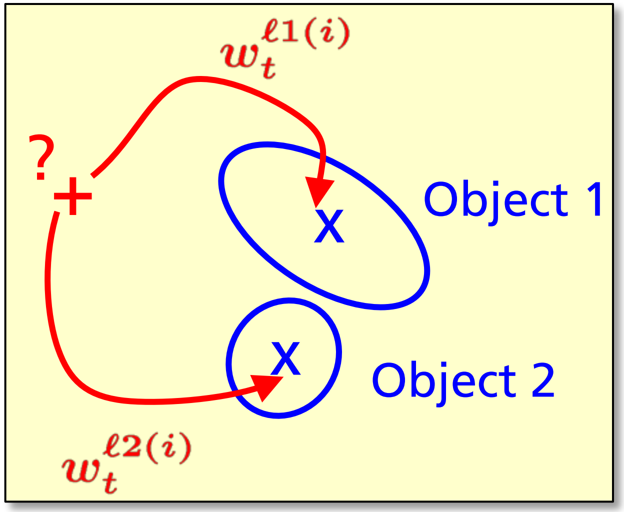


Complete PMHT-E Iteration

E-Step: Compute Assignment Probabilities

$$w_t^{rm(i)} = \frac{\pi_t^{m(i)} \mathcal{N}\left(\mathbf{z}_t^r; \mathbf{H}\mathbf{x}_t^{m(i)}, \mathbf{X}_t^{m(i)} + \mathbf{R}\right)}{\sum_{m'=0}^{M} \pi_t^{m'(i)} \mathcal{N}\left(\mathbf{z}_t^r; \mathbf{H}\mathbf{x}_t^{m'(i)}, \mathbf{X}_t^{m(i)} + \mathbf{R}\right)}$$

Dependent on Extent Estimate



M-Step: Optimize State Estimates

1. Run a **Bank of M Bayesian Extended Target Filters** (one per Target) using Synthetic Measurements and Spread Matrices

   Result: $\left[\mathbf{x}_1^{m(i+1)}, \ldots, \mathbf{x}_T^{m(i+1)}\right], \left[\mathbf{X}_1^{m(i+1)}, \ldots, \mathbf{X}_T^{m(i+1)}\right] \forall m$

2. Update **Mixing Proportions** for each Target

   Result: $\left[\pi_1^{m(i+1)}, \ldots, \pi_T^{m(i+1)}\right] \forall m$

Fusion: Kinematics Attributes

Given

Kinematic States of the observed Persons

$$\mathcal{X} = \mathcal{X}_{1:T} = \{\{\mathbf{x}_t^1, \ldots, \mathbf{x}_t^S\}\}_{t=1}^T$$

Attribute-Output $\mathbf{o}_t^{\text{ch}}$ of the Chemo-Sensors, $\text{ch} \in [1:5]$

$$\mathbf{o}_t^{\text{ch}} \in \{ \quad , \quad , \quad , \quad , \quad \} \qquad t \in [1:T]$$

Wanted

Classification Matrix $\mathrm{C} \in [0,1]^{5 \times S}$

Persons

Alert Levels	1	2	3
No Alert			
Alert I			
Alert II			
Alert III			
Alert IV			

Probability that Person 3 has Attribute

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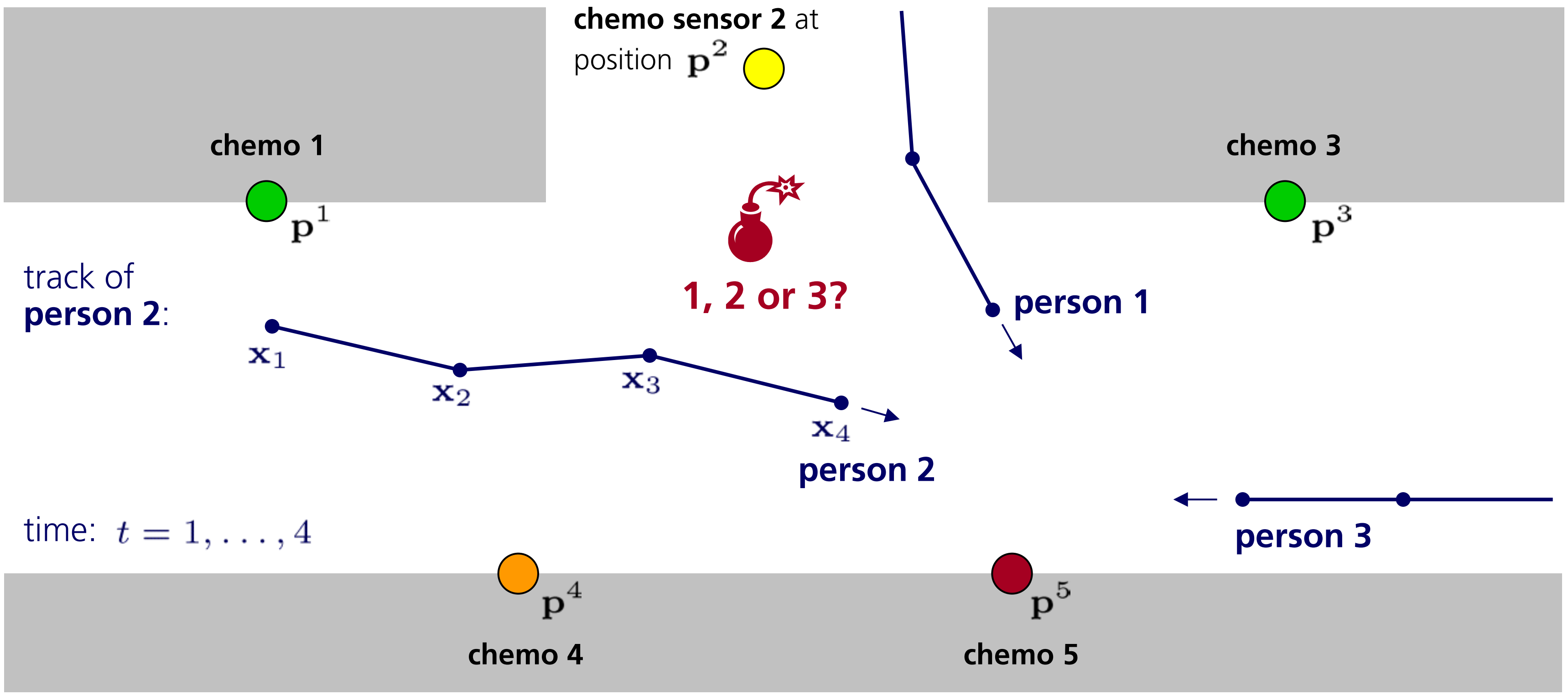
Classification problem: Who is carrying the bomb?

Fuse all position & signature measurements over space & time!

Position measurements: reconstruction of the kinematic behaviour

CBRNE signatures: low space-time resolution → non-trivial association



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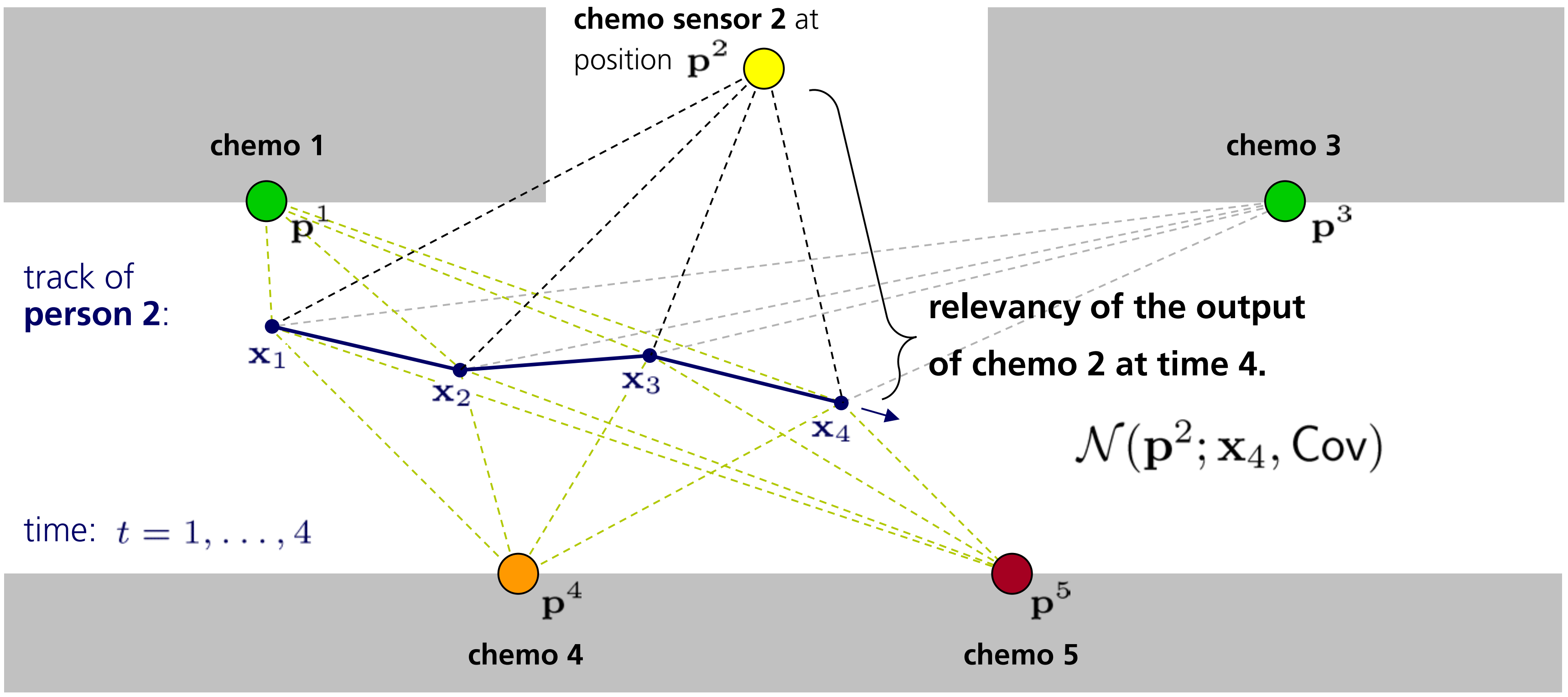
Solve the association problem via *Expectation-Maximization*!

Basis: Calculate relevancy of the signatures of each chemo sensor at all instants of time for each individual person.



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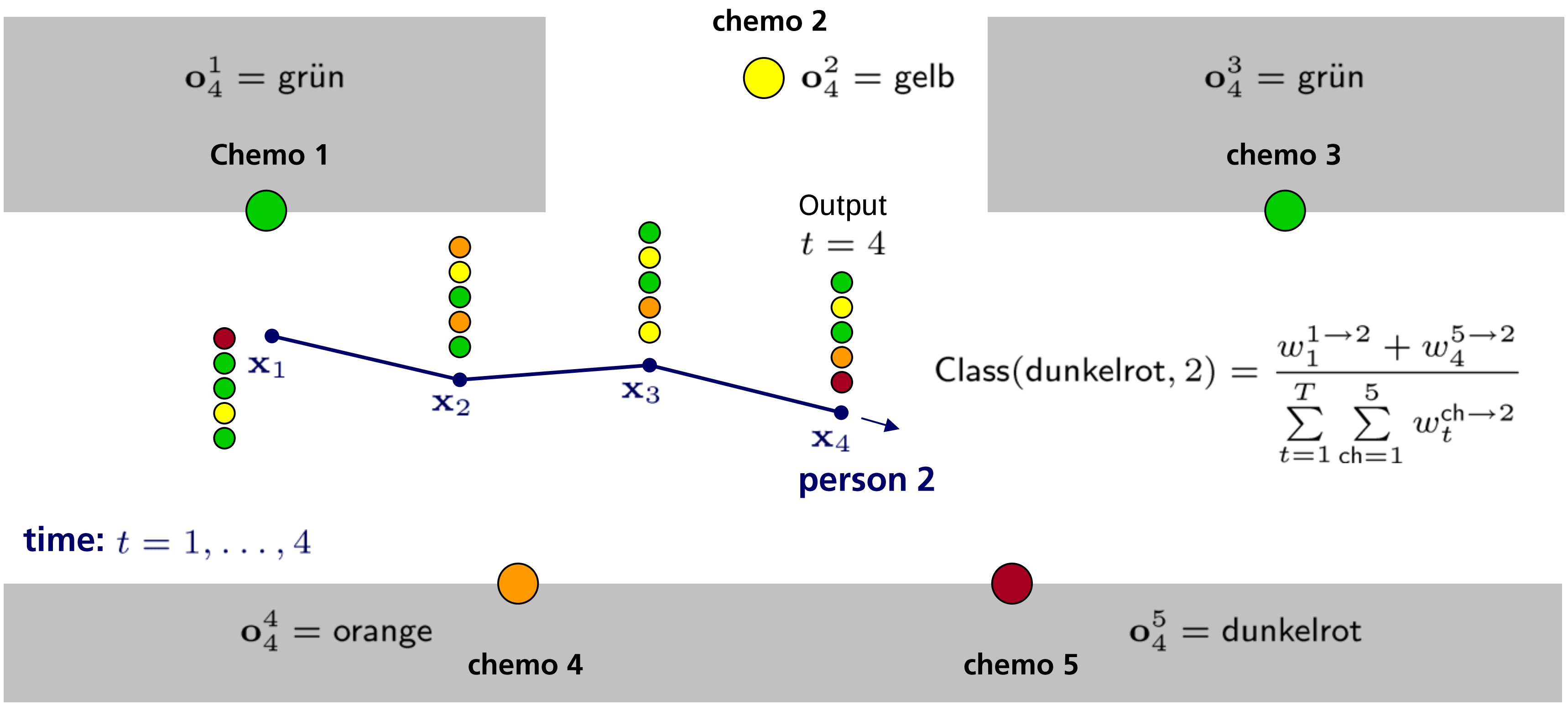
Fusion of position attribut measurements

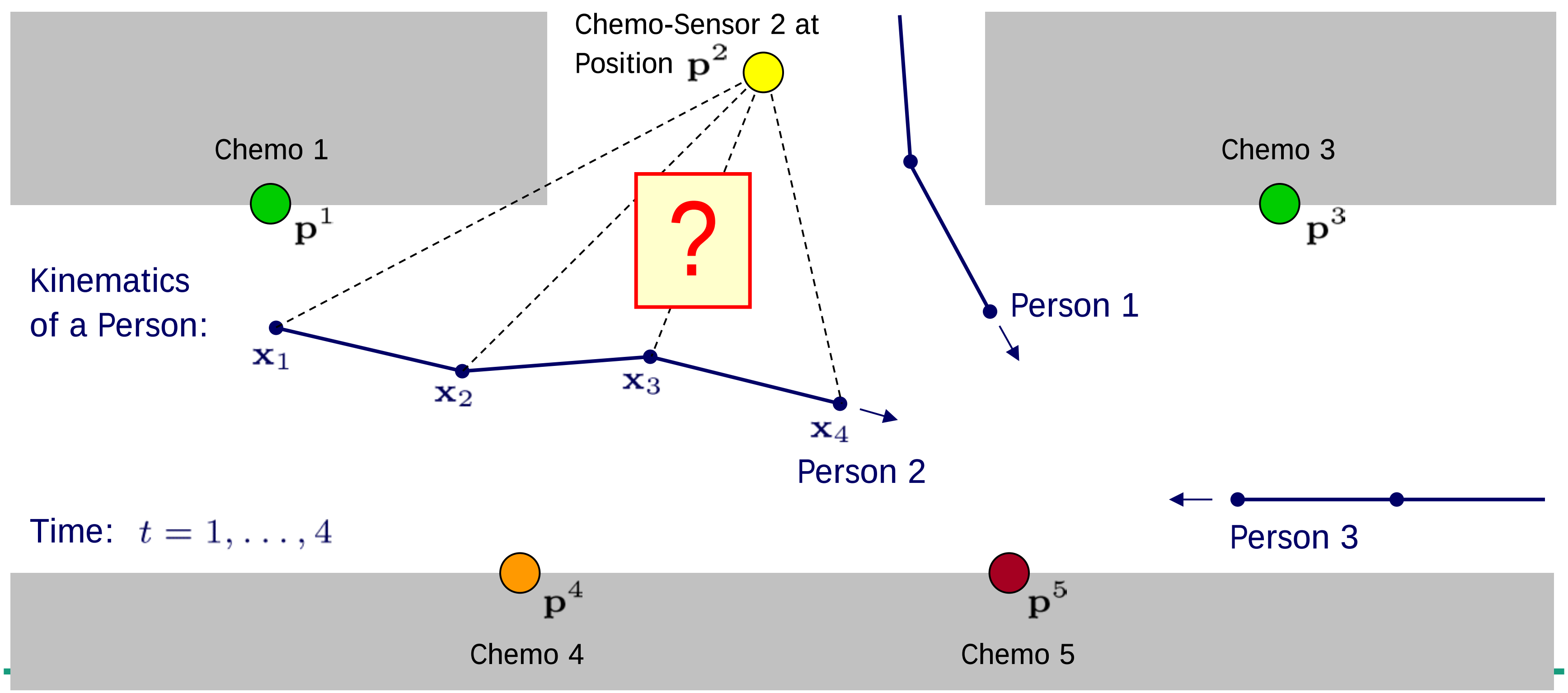
Iteratively calculate the classification matrix for each person while tracking in a unified approach (EM).



Fusion with chemo sensors: Problems when going to reality

Remark Assignment weight calculation is a difficult task that requires knowledge and models of the behavior of chemo sensors.

Influences Not only distance, but also velocity, temperature, humidity, turbulence, number of persons, ...: strong impact on **delay.**



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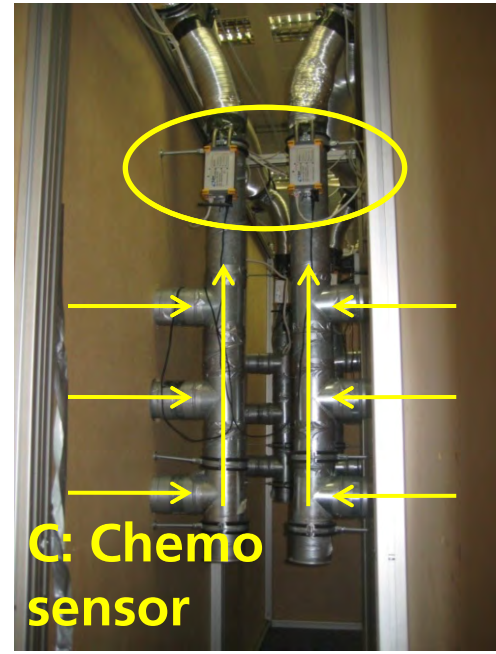
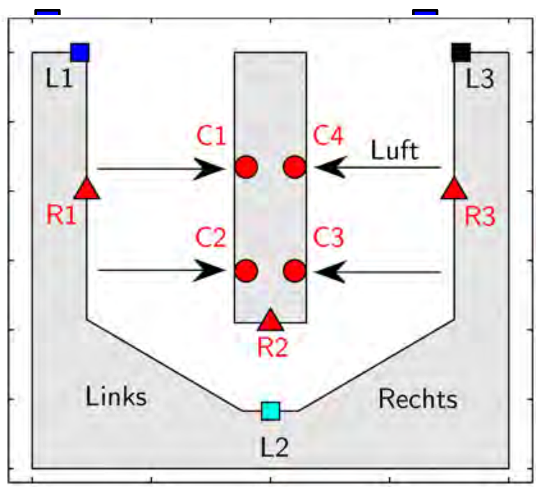
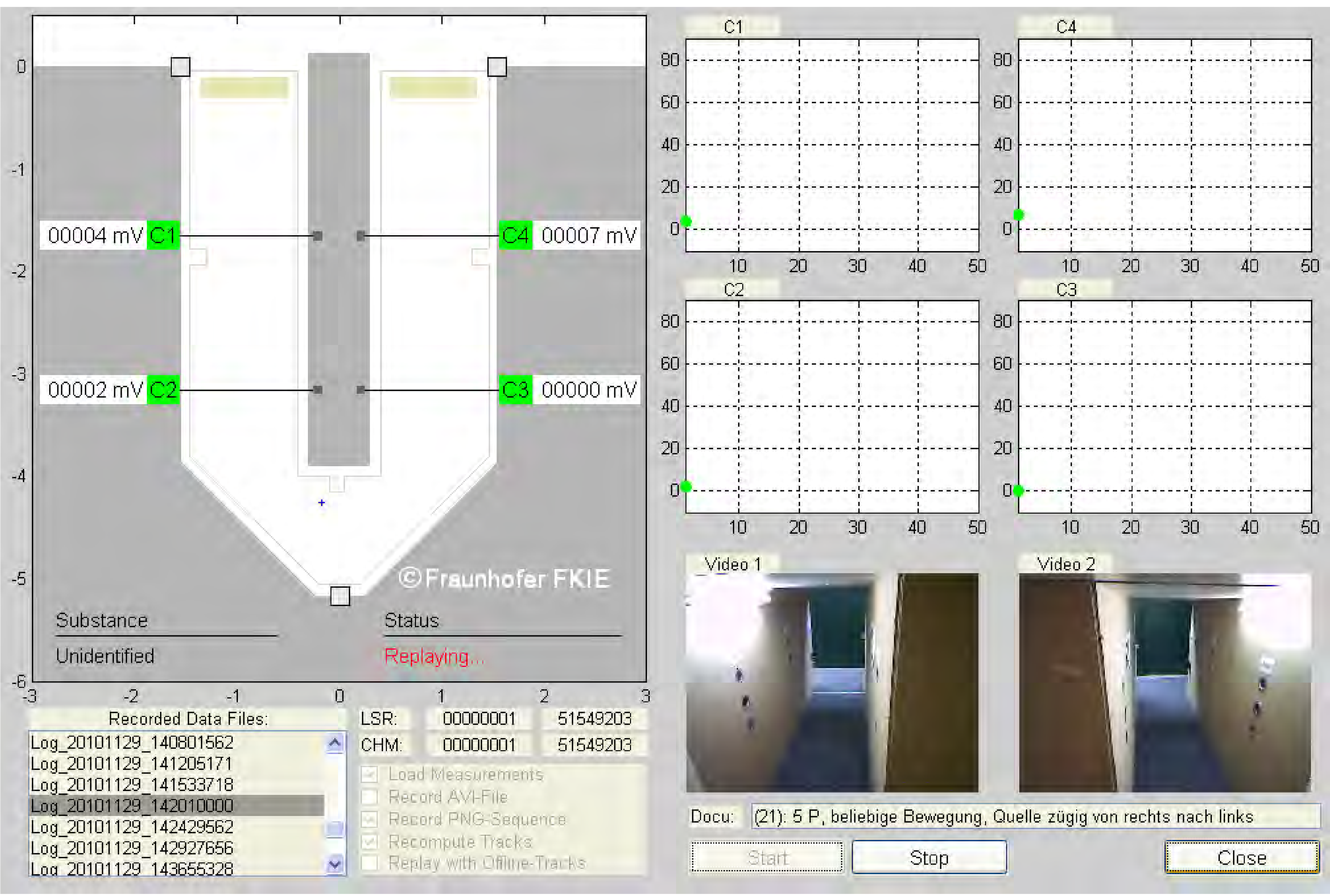
First Experimental Set-Up






00004 mV C1
C4 00007 mV
00002 mV C2
C3 00000 mV
©Fraunhofer FKIE
Substance
Status
Unidentified
Replaying...
C1
C4
C2
C3
Video 1
Video 2
Recorded Data Files:
Log_20101129_140801562
Log_20101129_141205171
Log_20101129_141533718
Log_20101129_142010000
Log_20101129_142429562
Log_20101129_142927656
Log_20101129_143655328
LSR: 00000001 51549203
CHM: 00000001 51549203
Load Measurements
Record AVI-File
Record PNG-Sequence
Recompute Tracks
Replay with Offline-Tracks
Docu: (21): 5 P, beliebige Bewegung, Quelle zügig von rechts nach links
Start
Stop
Close

HAMLeT – Example for “Law-Compliance by Design“?

Persons: NO collection of biometric parameters
Tracking: only kinematic quantities in the corridor

Goal: association of a hazardous material signature
No sensors (yet?) for individual person “smells”

HAMLeT system is “blind“ for “normal people“

Reconquer the possibility of “normal” public life
False alarms: manual control of a few persons

HAMLeT – Example for “Law-Compliance by Design“?

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Reconquer the possibility of “normal” public life
False alarms: manual control of a few persons

Problem: How to act when a threat is recognized?
(semi-) automated action procedures “Robo-Ethics“?

Who is allowed to live under the “security umbrella”?
How to standardize “Law-Compliance by Design“?
How to manage permission, approval, control?

Socio-cultural Awareness: societal acceptance

Collaboration Projects VeSPer and VeSPer Plus

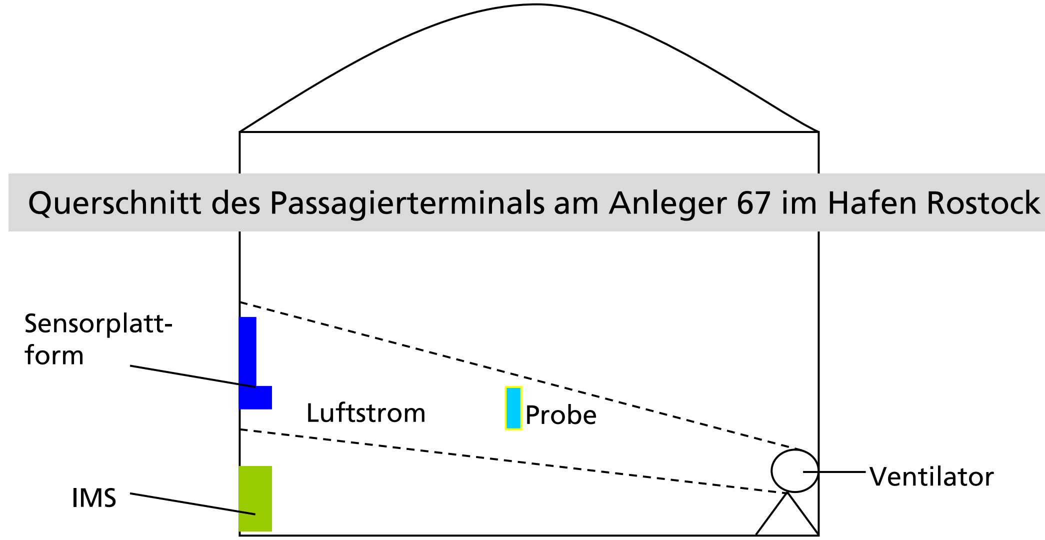
Verbesserung der **S**icherheit von **Per**sonen in der Fährschifffahrt

PROJEKTTRÄGER FÜR DAS

Bundesministerium
für Bildung
und Forschung

Fraunhofer
FKIE

Projekt VeSPer



Radioactive Material as Potential Terrorist Threat

Dirty Bomb

Localization?

- **Radioactive dispersion devices (RDD / "Dirty Bomb")**
  - ⇨ Combination of conventional explosives with radioactive material
  - ⇨ High damage potential: contaminated areas, health damage, psychology
- **RDDs have not yet been used but growing concerns (EU Project CATO)**
  - ⇨ Radioactive material readily available for medical / commercial use
  - ⇨ Numerous incidents involving loss or theft of radioactive sources
- **Localization of radioactive material in public spaces, good streams**

Panikmache oder Bedrohung?

Terroristen bereiten Anschläge mit "schmutzigen Bomben" vor

(BS/Uwe Kranz) Schon der Gedanke daran lässt einen frösteln: Immer wieder wird davor gewarnt, dass islamistische Terroristen den Bau einer "schmutzigen Bombe" planten oder gar vorbereiteten: Ein konventioneller Sprengsatz, der mit radioaktivem Material vermischt ist. Was ist daran wahr?

Unbestreitbar hat bereits 2003 einer der "Urväter" des Daesh und heutigen sogenannten "Islamischen Staates", der Jordanier *Abu Musab al-Zarqawi*, als Führer der arabischen Fraktion der Ansar-al-Islam-Bewegung im Irak am Bau solcher Bomben gearbeitet. In Jordanien wurde eines seiner Teams verhaftet. 20 Tonnen Sprengstoff und Chemikalien konnten sichergestellt werden. *Al Zarqawis* Männer sollten einen Anschlag auf die Hauptstadt Amman durchführen, der circa 80.000 Menschen das Leben hätte kosten können. Seine Planungen für den Einsatz einer "schmutzigen Bombe" konnte er nicht mehr beenden, er wurde im Juni 2006 bei einem US-Luftangriff auf das irakische Hibhib getötet.

Der dschihadistische Todeskult versucht seit Ende der 1990er-Jahre bis heute, einen nuklearen Terroranschlag durchzuführen. Das musste selbst die Bundesregierung auf eine parlamentarische Anfrage zum Interesse von Terroristen an chemischen, biologischen, radioaktiven und nuklearen Stoffen hin einräumen. Sie beschwichtigte allerdings sogleich auch, dass keine Erkenntnisse zu konkreten islamistisch motivierten Anschlagsvorhaben in Deutschland vorlägen.

Serie
TERRORZIELE (TEIL 2)

Leicht zu erwerben

Zahlreiche verdeckte Ermittlungen zeigten jedoch, dass die Anbieter keine Skrupel hatten, einem angeblichen Daesh-Terroristen für 2,5 Millionen US-Dollar radioaktives Material und Blaupausen für den Bombenbau zu verkaufen. Auch aus anderen Teilen der ehemaligen Sowjetunion soll bis 2011 solches Material zum Kauf angeboten worden sein, sogar hoch angereichertes Uran-235. Nach Erkenntnissen internationaler Ermittler war die Rede von bis zu zehn Kilogramm Uran. Das entspricht einem Fünftel der Bombe von Hiroshima! Im Nahen Osten sorgte ein anderer Bericht für Schlagzeilen: Unbekannte hatten bereits 2015 einer US-Firma im irakischen Basra geringe Mengen radioaktives Iridium-192 gestohlen. Die Internationale Atomenergie-Agentur IAEA fahndet bis heute erfolglos nach Material und Täter.

Der aktuelle Bericht der Nuclear Threat Initiative (NTI) wiederum warnt vor den "signifikanten Lücken" bei der Sicherheit radiologischer Materialien, die in "zehntausenden Anlagen in mehr als 100 Ländern" lagerte.

Erhebliche psychologische Folgen

Anschläge mit "schmutzigen Bomben" würden nach Expertenmeinung nicht allzu viele Todesopfer fordern, aber Milliardenschäden und eine verheerende psychologische Wirkung verursachen. Der Daesh hat sich daher seit Jahren einen technischen, logistischen und personellen Unterbau geschaffen, um einen solchen Anschlag vorzubereiten.

Uwe Kranz ist der Terrorexperte des Behörden Spiegel. Zuvor war der Leitende Ministerialrat a. D. Präsident des Landeskriminalamtes Thüringen und nationaler Experte bei Europol.

Foto: BS/Dombrowsky

In Europa zeigt sich das besonders deutlich in Belgien: Im Kernkraftwerk Doel arbeitete jahrelang der Belgier marokkanischer Abstammung und radikale Islamist *Ilyass Boughalab*, bevor er sich 2012 zum Daesh absetzte, wo er 2014 getötet wurde. Im Atomkraftwerk war er sogar in der Hochsicherheitszone tätig. Ein weiterer Mitarbeiter wurde wegen terroristischer Aktivitäten zu einer kurzen Freiheitsstrafe verurteilt. Im August 2014 sabotierten Unbekannte einen Reaktorblock: Manuell wurden 65.000 Liter Öl abgelassen, um die Turbinen zu überhitzen. Das Computersystem der belgischen Nuklearbehörde wurde gehackt. Im Dezember 2014 wurden Drohnenflüge über dem Kraftwerk gemeldet.

Entführung

Im November 2015 wurde bekannt, dass der Leiter des Nuklearforschungszentrums SCK-CEN in Mol mit einer Videokamera ausgespäht worden war. Vermutlich bereiteten die tatverdächtigen Brüder *Khalid* und *Ibrahim El Bakraoui* eine Entführung des Wissenschaftlers vor, um in dem Zentrum hergestellte Radionukleide zu erpressen. Ihre Wohnung war von dem Belgier *Mohamed Bakkali* angemietet worden, der gemeinsam mit dem Franzosen *Salah Abdeslam* und anderen auch am Attentat in Paris im November 2015 beteiligt war. In *Bakkalis* Wohnung wurde zudem ein Sprengstoffgürtel gefunden, an dem DNA-Spuren von *Abdeslam* gesichert werden konnten.

Nuklearterrorismus nicht mehr weit weg

In seiner Wohnung sollen auch Unterlagen zum deutschen Atomforschungszentrum Jülich gefunden worden sein, was das Bundesamt für Verfassungsschutz (BfV) jedoch dementierte.

Dramatisch daran ist, dass sich nunmehr die operative Ebene des Daesh mit Nuklearanschlägen befasst. Der atomare Terrorismus ist, nach dem mysteriösen Terrorangriff im Jahr 2007 auf das nukleare Forschungszentrum Pelindaba in Südafrika, nun auch in Europa in greifbare Nähe gerückt. Das ist auch im Lichte der Ankündigung des Kalifen *Ibrahim* zu sehen, dass das Jahr 2016 noch chaotischer werde als 2015.

Die deutschen Vorbereitungen zur Verbesserung der nuklearen Sicherheit laufen auf Hochtouren. Die Bundesregierung überarbeitete das Konzept "Zivile Verteidigung", 2014 wurden auf Bundesebene eine Plattform zum Schutz von atomaren, biologischen oder chemischen Gefahren (CBRN) eingerichtet, sichere Warnmeldesysteme installiert sowie Krisenstrukturen und -pläne aktualisiert.

Eines steht also zweifelsfrei fest: Die Gefahr wächst. Je mehr der Daesh in seinem Herrschaftsgebiet unter Druck gerät, desto größer ist die Wahrscheinlichkeit, dass er mit einem Befreiungsschlag in Europa versucht, seine "Handlungsfähigkeit" zu beweisen.

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR
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REASTRAIN

Resilience of the Franco-German High Speed Train Network

Fraunhofer
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FKIE Contribution to RE(H)STRAIN: Detection of dirty bombs

WP 8.3 + 8.4 'Development of a security concept based on multiple sensor data fusion' and 'Detection of dirty bombs'

Exploitation of heterogeneous sensors:

fusion algorithms for situation picture production

➔ Threat assessment

Sensor to be used:

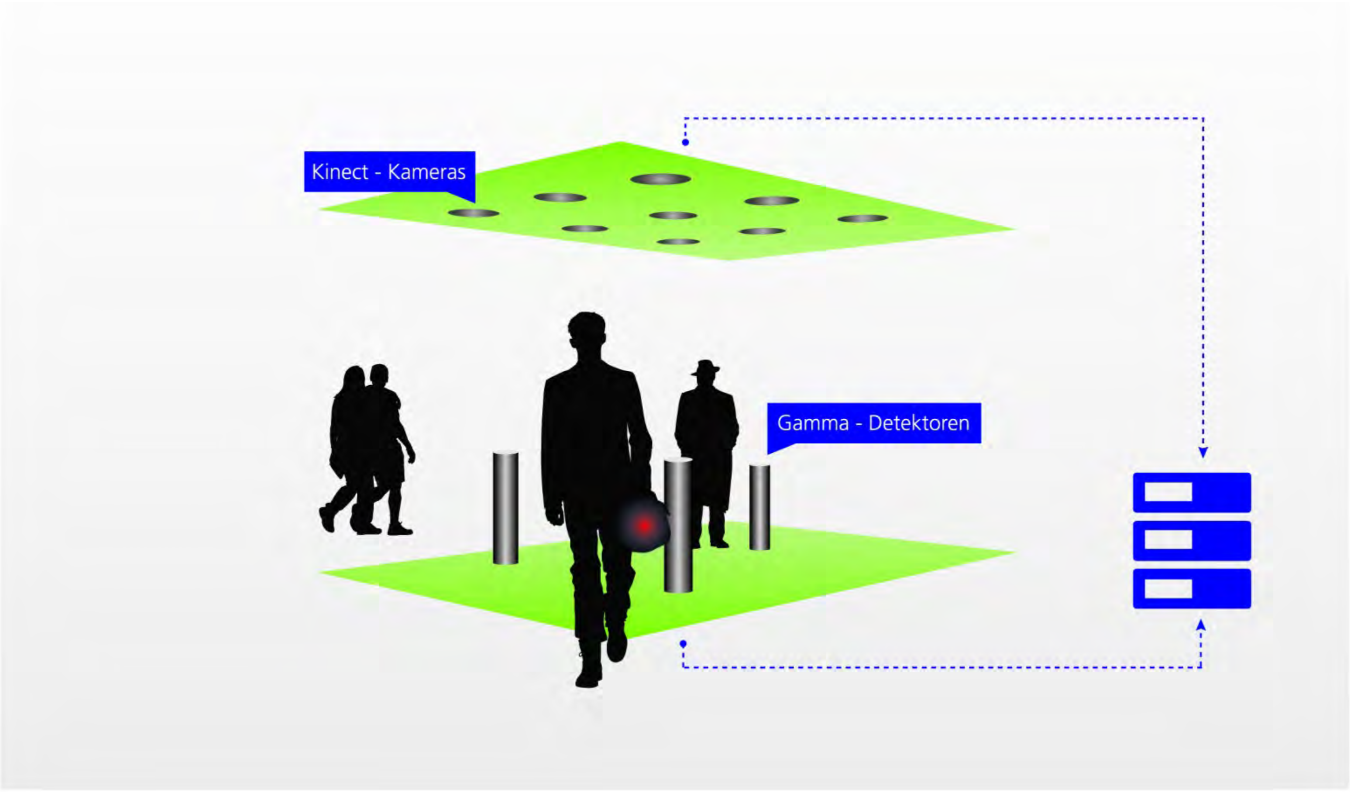
1. ***Kinect cameras (kinematic data)***
   Installation above the observed area (looking-down)
   ➔ *Localization and tracking of single persons (no collection of personal data, e.g. face recognition algorithms not applicable)*
2. ***Gamma spectrometers (attribute data)***
   Detection of radioactive nuklides: ^{60}Co, ^{137}Cs

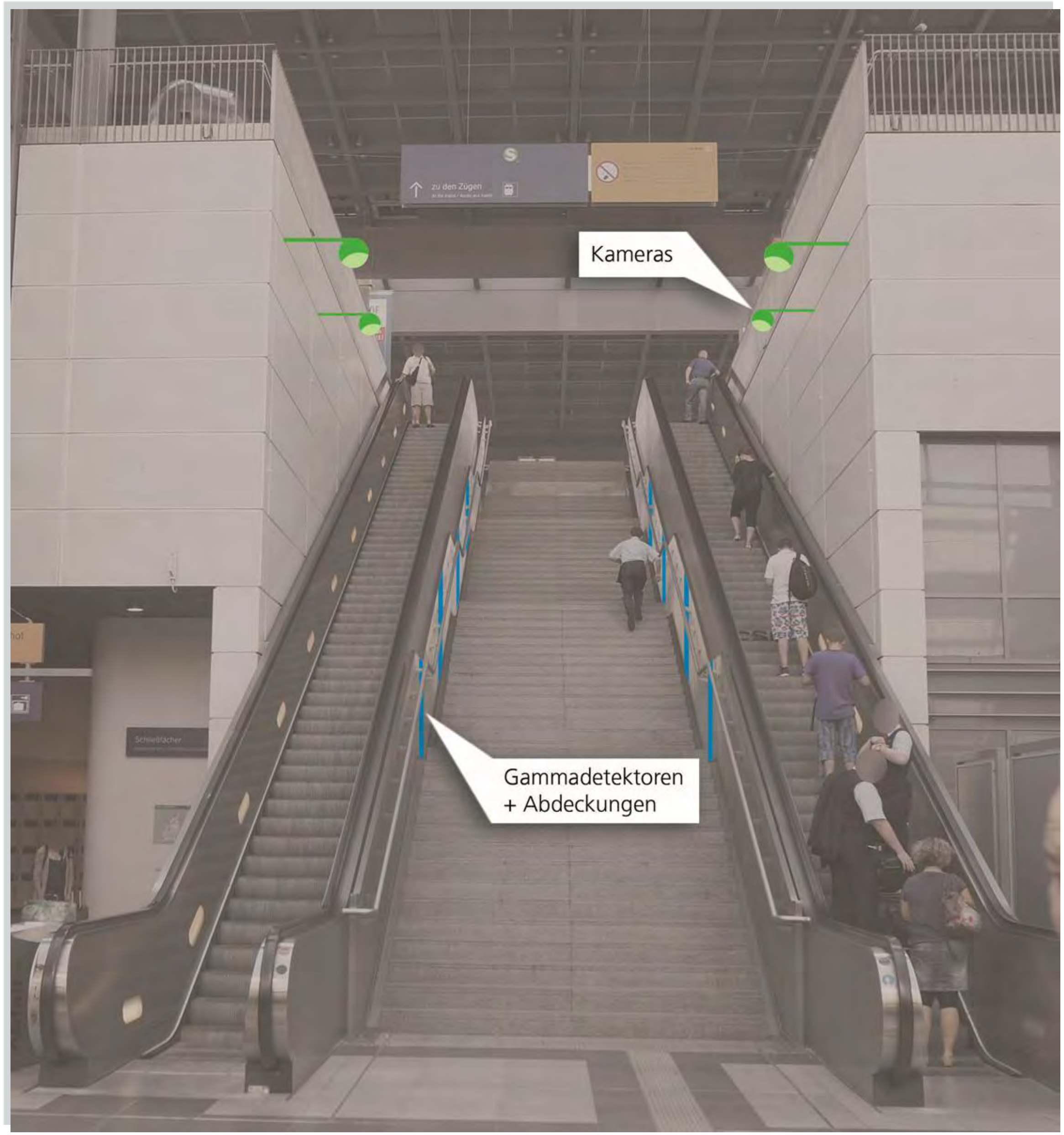
Data fusion: measurements of gamma spectrometers + Kinect-cameras

➔ *"dirty bomb" can unambiguously be associated to a person.*

RE(H)STRAIN: Detection of "dirty bombs"

Concept of a surveillance system for "dirty bombs"





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acting human beings

perceive achieve

A fundamental ethical notion: responsibility

Literal meaning: Being requested to respond to questions on the effects of own actions at court.

First associations:

What is the duty, who is judging and accusing according to which law?

What about resulting praise or punishment?

Elements of thought:

Only free beings can take over any responsibility:

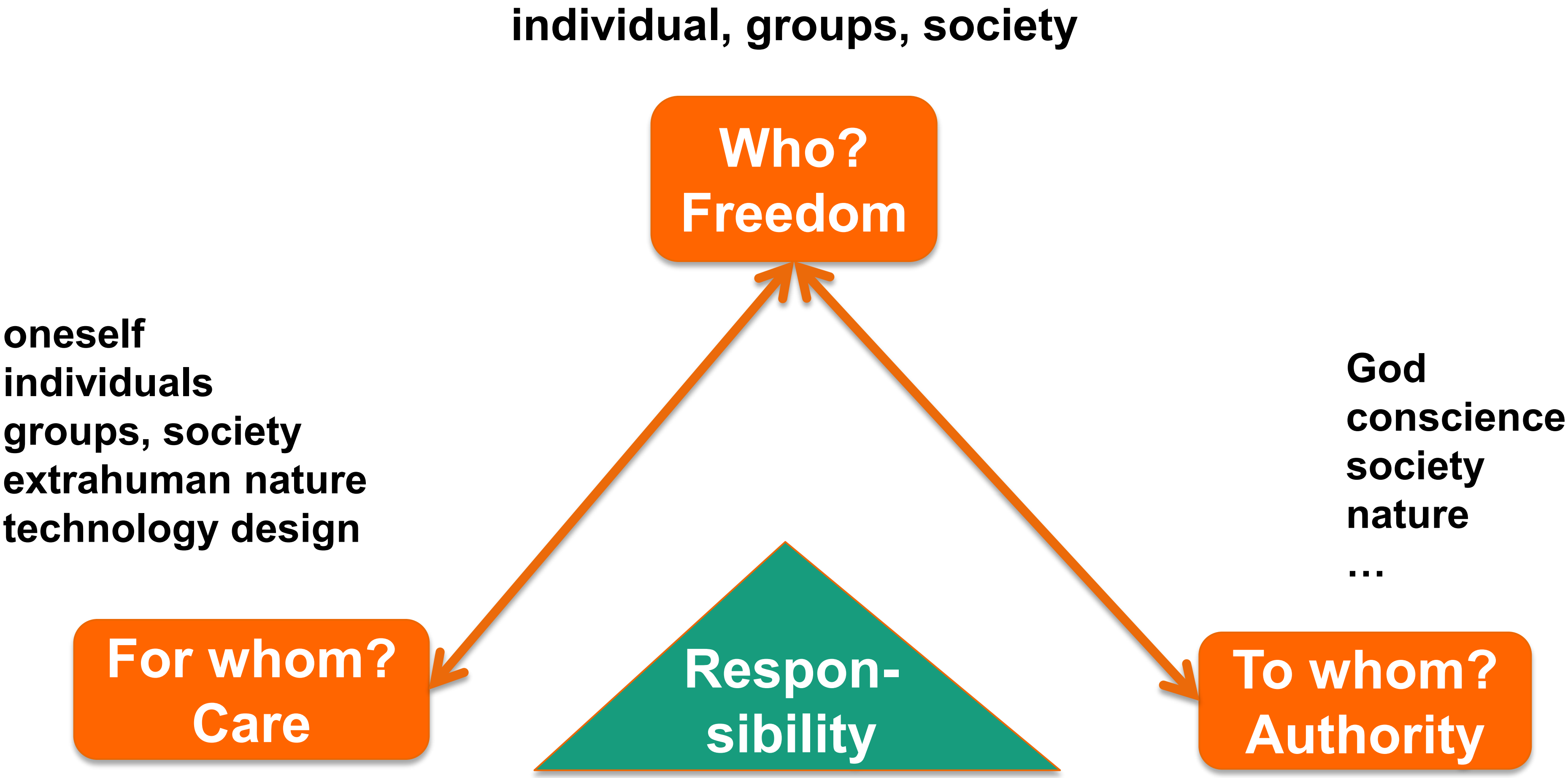
Readiness of interior acceptance of rules / laws.

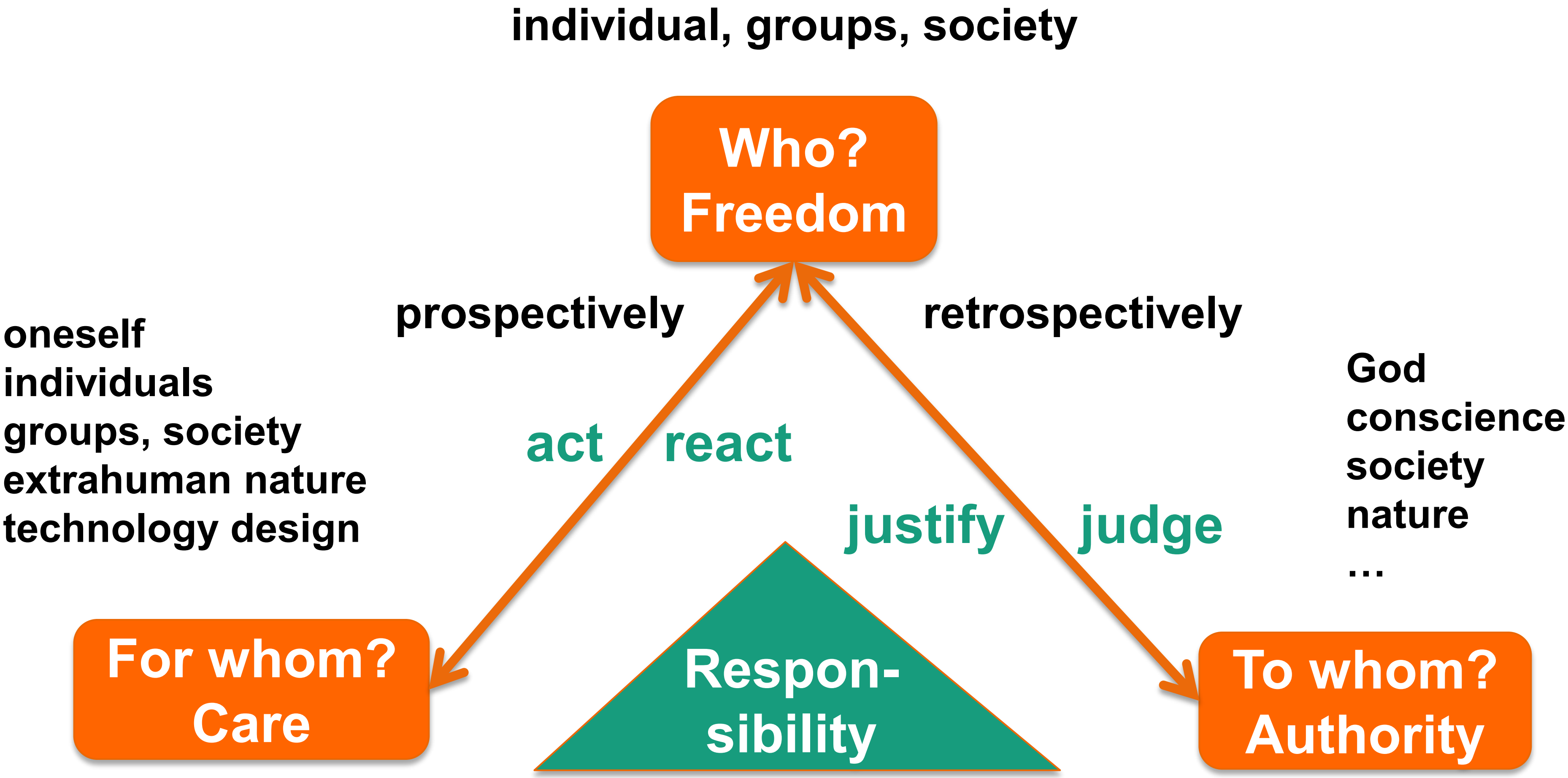
Behaving well also when external rules are missing or mutually conflicting.

Good: Overarching notion?

“In the end, everybody is alone with his freedom …”

mission, environment


individual, groups, society
Who?
Freedom
oneself
individuals
groups, society
extrahuman nature
technology design
God
conscience
society
nature
…
For whom?
Care
Respon-
sibility
To whom?
Authority


individual, groups, society
Who?
Freedom
prospectively
retrospectively
oneself
individuals
groups, society
extrahuman nature
technology design
act
react
justify
judge
God
conscience
society
nature
…
For whom?
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sibility
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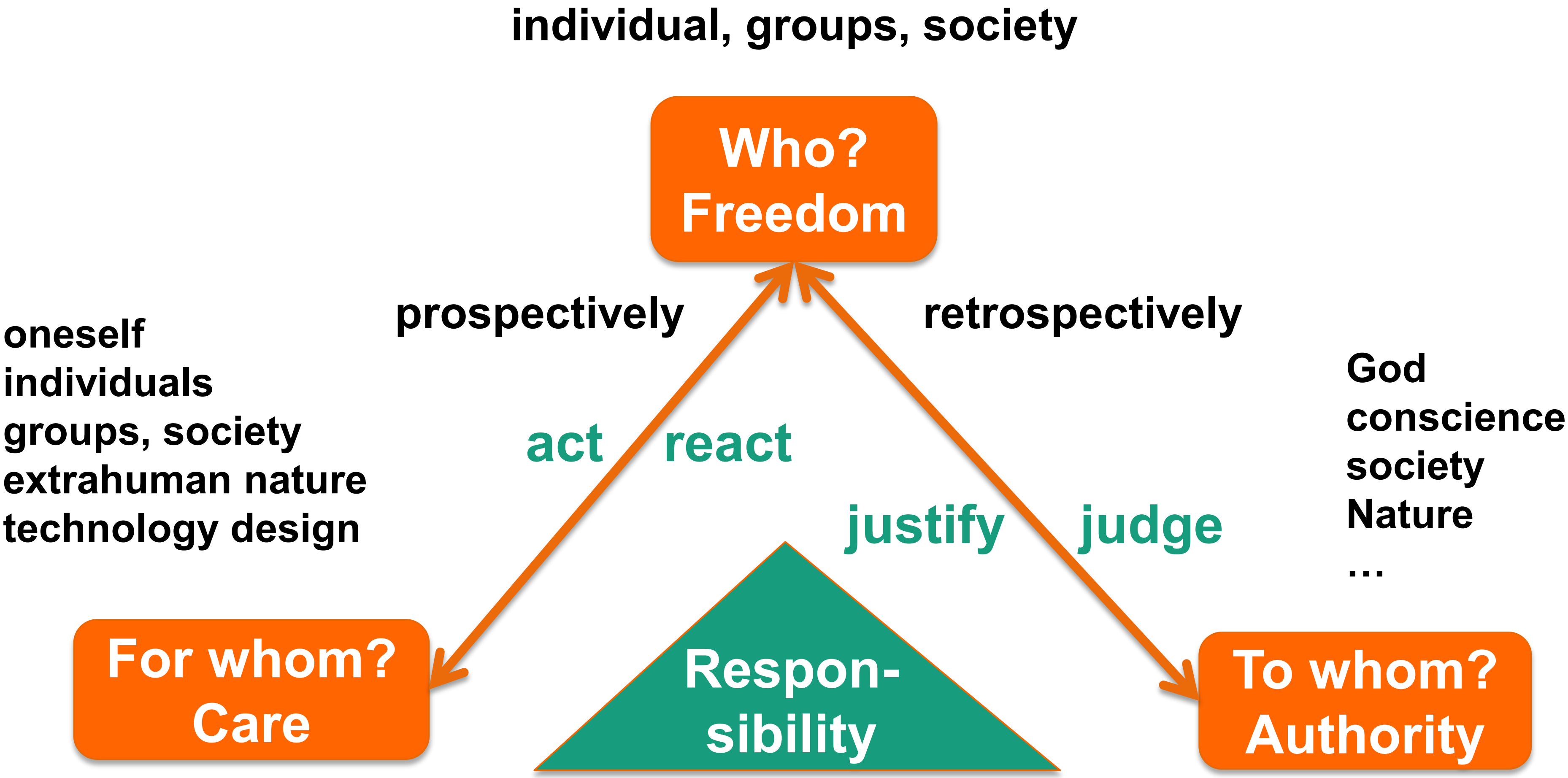
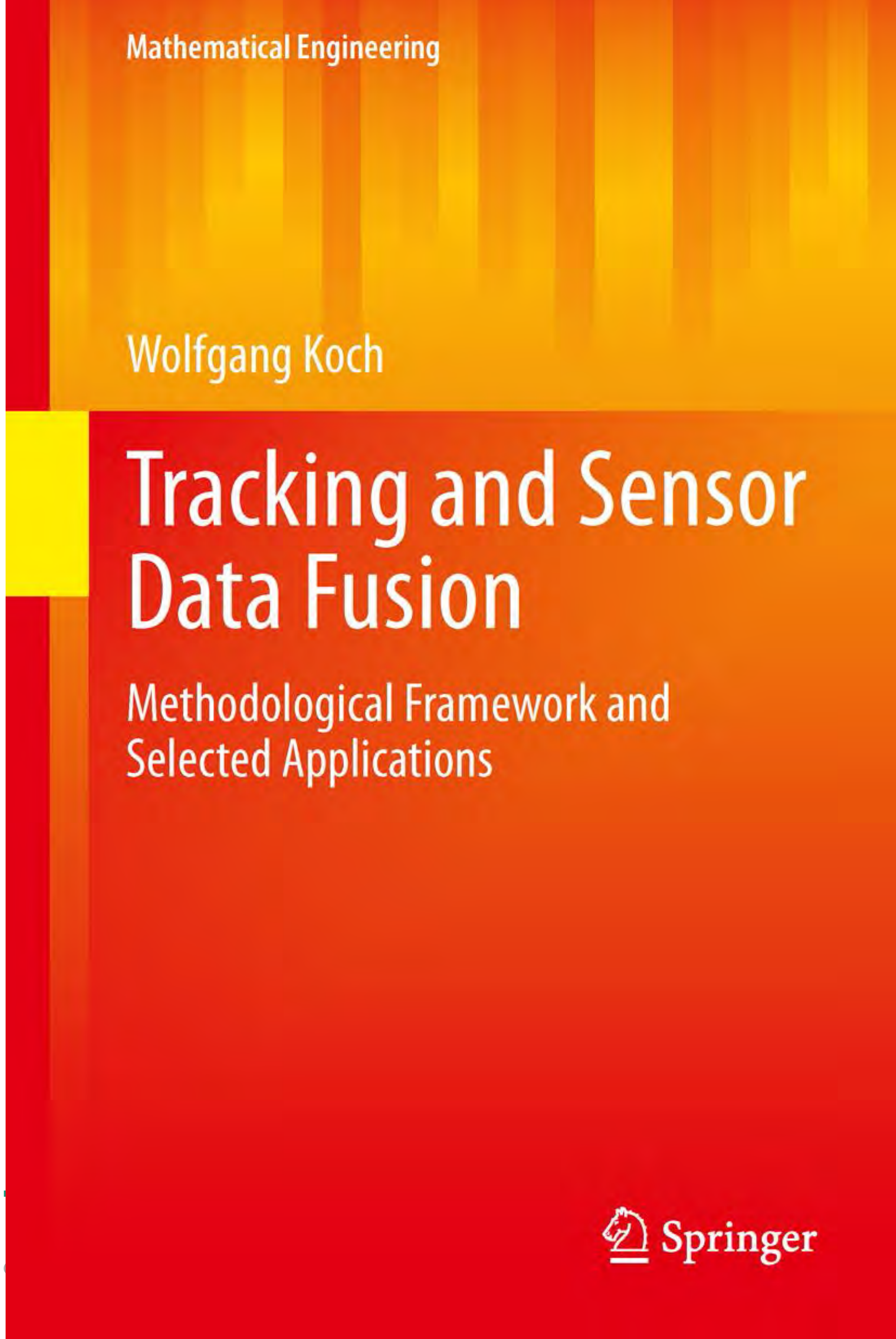


Notions of keeping a society balanced: Responsibility versus Liability:

elements of insight, personal commitment, comprehensive care

Insight, freedom, self-reflectivity, dialog, merit / guilt, carelessness:

“Assist” humans to act responsibly, e.g. hard & soft fusion!



Many topics of previous work at Fraunkofer FKIE, Dept. *Sensor Data and Information Fusion.*

Appeared in 2014.

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