# SLAM IN AIR VEHICLE APPLICATIONS

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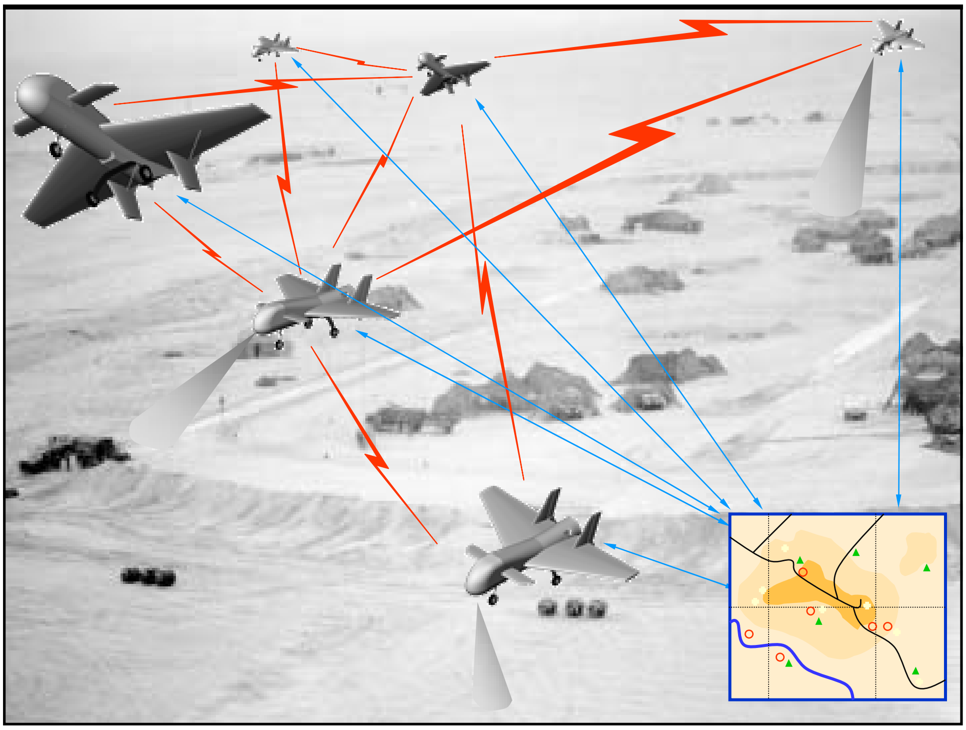
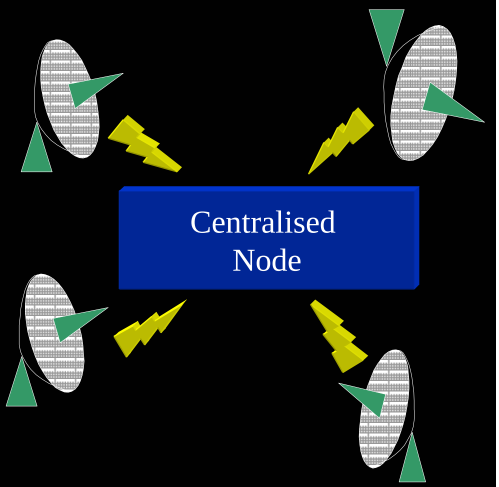


# Centralised Data Fusion

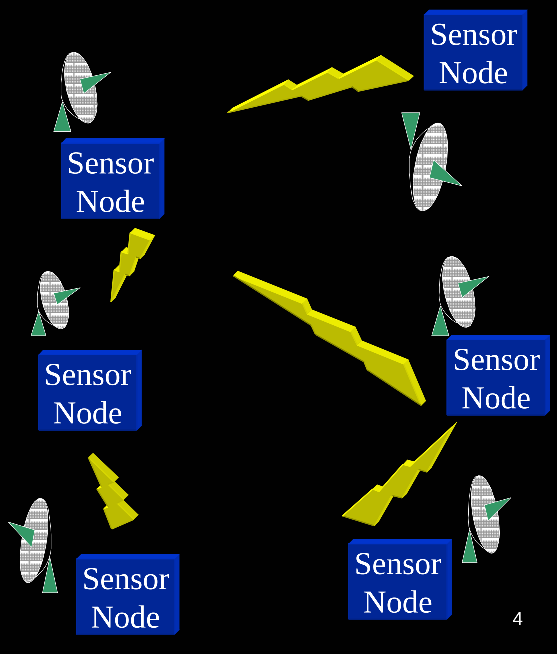
- Excessive Communication Bandwidth
- Excessive Computational Expense
- Low Level of Integrity






# Decentralised Data Fusion

- Increased Integrity
- Reduction in computation and communication expense
- Wider coverage area
- Results are obtained quicker



# Physical System

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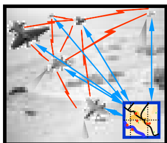

# Flight Platforms

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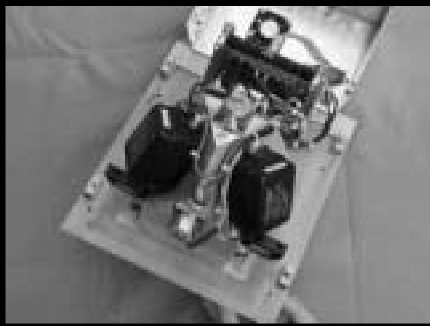
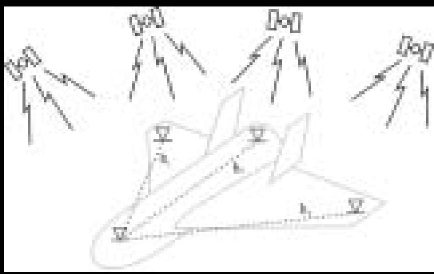
# INS/GPS





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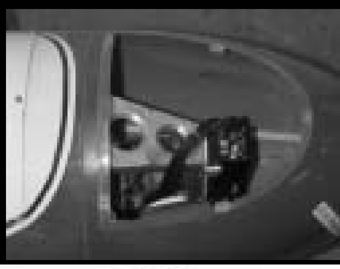
# Vision + Laser/Vision Sensors



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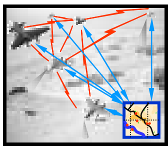
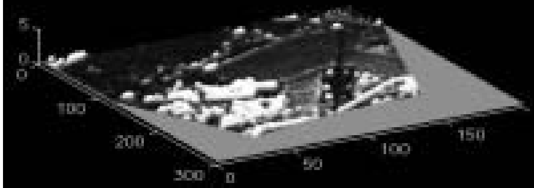
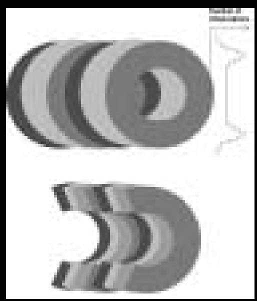


# Radar Sensor



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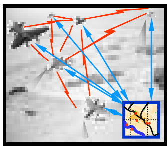
# Simultaneous Localisation and Map Building

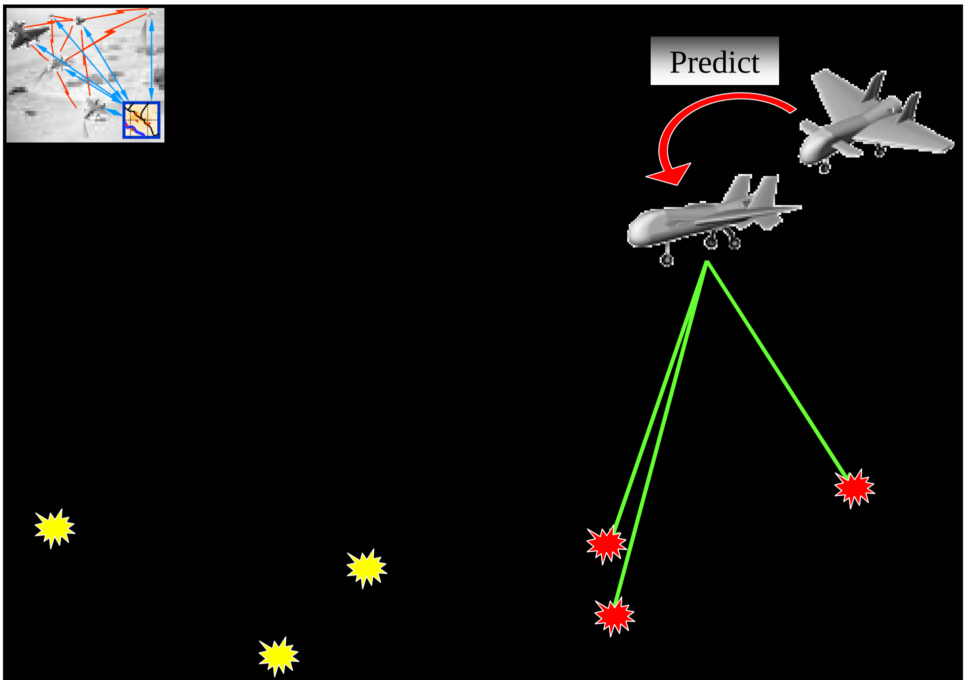


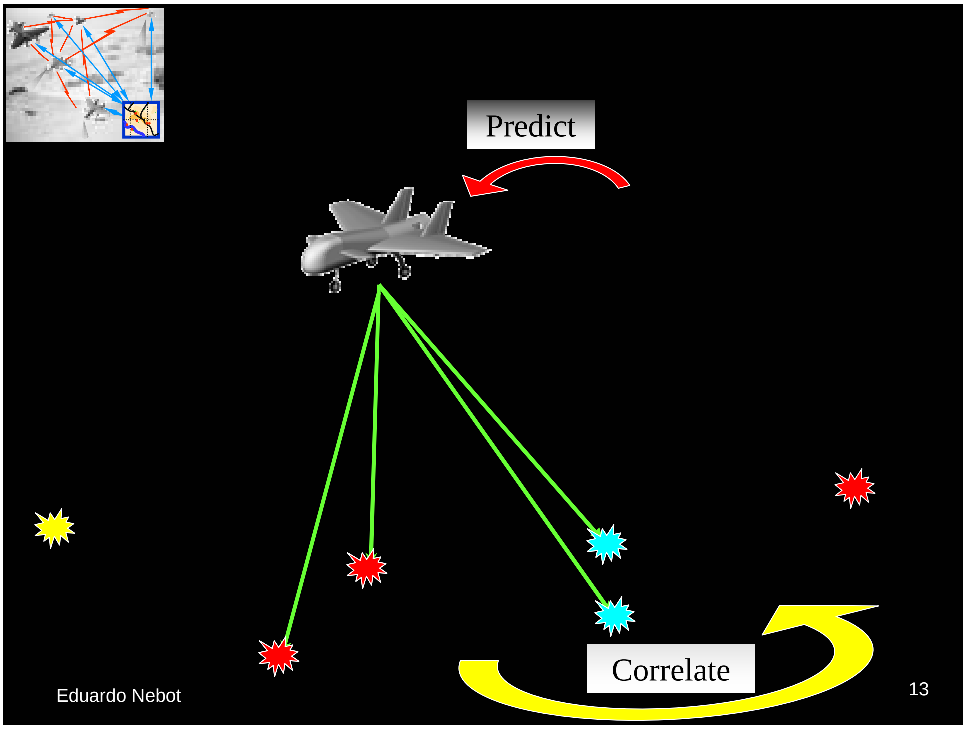
# SLAM

- Highly non-linear
- 6DoF Estimation
- Information is only $2^{1/2}$D
- Observability Issues

- Standard Cartesian
- Raw Fusion






Predict
Correlate
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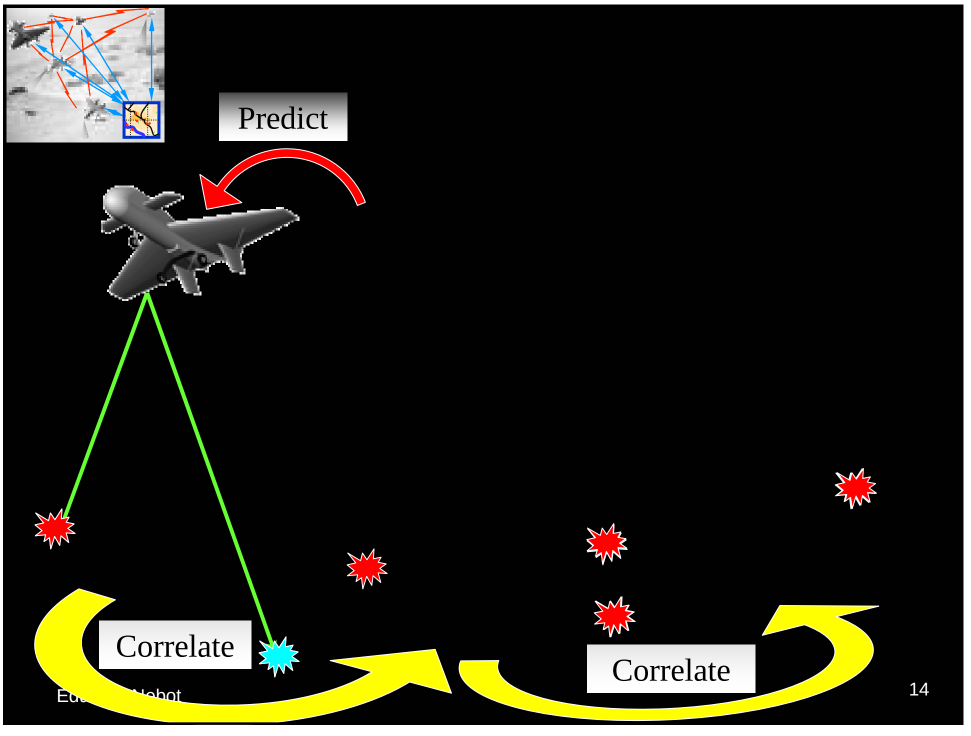
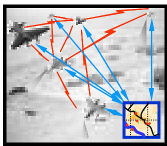
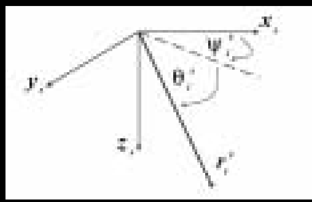
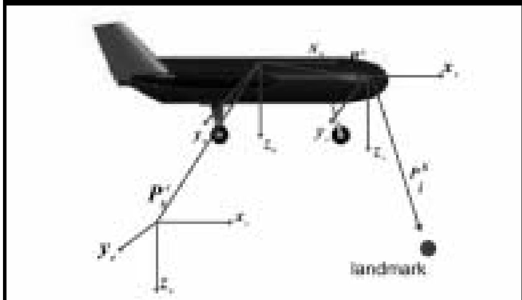

Predict
Correlate
Correlate
14



# SLAM






$$\mathbf{p}_i^n = \mathbf{P}_b^n + \mathbf{C}_b^n \mathbf{P}_s^b + \mathbf{C}_b^n \mathbf{C}_s^b \mathbf{p}_i^s$$

$$\dot{P}_b^n = \mathbf{V}_b^n$$
$$\dot{V}_b^n = \mathbf{C}_b^n \mathbf{f}_b$$

$$\dot{\phi} = \omega_x + (\omega_y \sin\phi + \omega_z \cos\phi)\tan\theta$$
$$\dot{\theta} = \omega_y \cos\phi - \omega_z \sin\phi$$
$$\dot{\psi} = \frac{\omega_y \sin\phi + \omega_z \cos\phi}{\cos\theta}$$

$$\mathbf{x}(k) = [\ \mathbf{x}_v^T(k)\ \ \mathbf{p}_1^T(k)\ \ \mathbf{p}_2^T(k)\ \ \ldots\ \ \mathbf{p}_N^T(k)\ ]^T,$$

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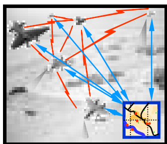

# SLAM – Error Analysis

$$\delta\mathbf{p}_i^n = \tilde{\mathbf{p}}_i^n - \mathbf{p}_i^n$$

$$\delta\dot{P}_b^n = \delta V_b^n,$$
$$\delta\dot{V}_b^n = [\mathbf{C}_b^n f_b \times]\delta\psi_b^n + \mathbf{C}_b^n \delta f_b,$$
$$\delta\dot{\psi}_b^n = -\mathbf{C}_b^n \delta\omega_b.$$

$$\delta\mathbf{p}_i^n = \delta\mathbf{P}_b^n + \mathbf{C}_b^n \delta\mathbf{P}_s^b + [\mathbf{C}_b^n \tilde{\mathbf{P}}_s^b \times]\delta\psi_b^n + \mathbf{C}_b^n \mathbf{C}_s^b \delta\mathbf{p}_i^s + [\mathbf{C}_b^n \mathbf{C}_s^b \tilde{\mathbf{p}}_i^s \times](\delta\psi_b^n + \delta\theta_s^b)$$

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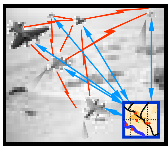


# INS/SLAM - Observation

- Non-linear observation model

$$z(t)=h(x(t))+v(t)$$

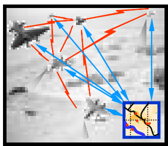
- Observation Model
  - In Cartesian coordinate

$$z_{cartesian} \equiv [x \quad y \quad z]^T = p_{ts}^s = C_s^{bT} C_b^{nT} [p_{t_i}^n - p_v^n - C_b^n p_{sb}^b]$$

  - In Spherical coordinate

$$z_{spherical} \equiv [r \quad \psi \quad \theta]^T = g_1(p_{ts}^s) = \begin{bmatrix} \sqrt{x^2+y^2+z^2} \\ \tan^{-1}(y/x) \\ \tan^{-1}(z/\sqrt{x^2+y^2}) \end{bmatrix}$$





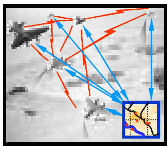
# INS/SLAM - Observation

- Jacobian In Cartesian coordinates

$$H_{cartesian} = \nabla_x h = \begin{bmatrix} -C_s^{bT} C_b^{nT} & 0_{3\times3} & \frac{\partial p_{ts}^s}{\partial \psi} & \cdots & (C_s^{bT} C_b^{nT})^i & \cdots \end{bmatrix}$$

- Jacobian In Spherical coordinates

$$H_{spherical} = \nabla_x h = \nabla g_1 \nabla g_2 = \begin{bmatrix} \frac{x}{r} & \frac{y}{r} & \frac{z}{r} \\ -\frac{y}{x^2+y^2} & \frac{x}{x^2+y^2} & 0 \\ \frac{-zx}{r^2\sqrt{x^2+y^2}} & \frac{-zy}{r^2\sqrt{x^2+y^2}} & \frac{\sqrt{x^2+y^2}}{r^2} \end{bmatrix} \begin{bmatrix} -C_s^{bT} C_b^{nT} & 0_{3\times3} & \frac{\partial p_{ts}^s}{\partial \psi} & \cdots & (C_s^{bT} C_b^{nT})^i & \cdots \end{bmatrix}$$



# INS/SLAM - EKF

- EKF formulation

$$x_{k+1} = f(x_k, u_{k+1}) + w_k$$
$$z_k = h(x_k) + v_k$$

- Prediction

$$x_{k+1} = f(x_k, u_{k+1})$$
$$P_{k+1|k} = \nabla_x f_k P_{k|k} \nabla_x f_k^T + \nabla_u f_k U_k \nabla_u f_k^T + Q_k$$

- Update

$$\nu_k = z_k - h(x_k)$$
$$S_k = \nabla_x h P_{k+1|k} \nabla_x h^T + R_k$$
$$W_k = P_{k+1|k} \nabla_x h^T S_k^{-1}$$
$$x_{k+1|k+1} = x_{k+1|k} + W_k \nu_x$$
$$P_{k+1|k+1} = P_{k+1|k} - W_k S_k W_k^T$$

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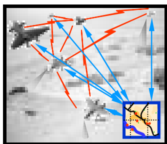

# INS/SLAM - EKF

- Data association

$$\nu_k^T S_k^{-1} \nu_k \le d_{min}$$

- New feature Augmentation

$$x_{new} = \begin{bmatrix} x_k \\ g(x_k, z_k) \end{bmatrix}$$

$$P_{new} = \begin{bmatrix} I & 0 \\ \frac{\partial g}{\partial x} & \frac{\partial g}{\partial z} \end{bmatrix} \begin{bmatrix} P_k & 0 \\ 0 & R_k \end{bmatrix} \begin{bmatrix} I & 0 \\ \frac{\partial g}{\partial x} & \frac{\partial g}{\partial z} \end{bmatrix}^T$$

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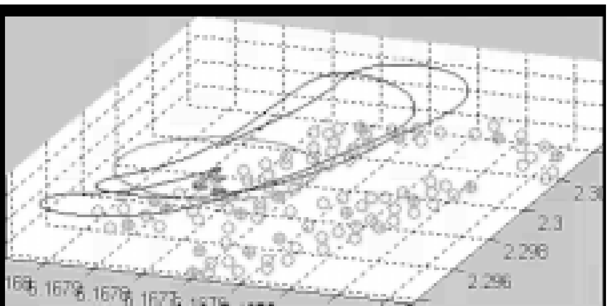
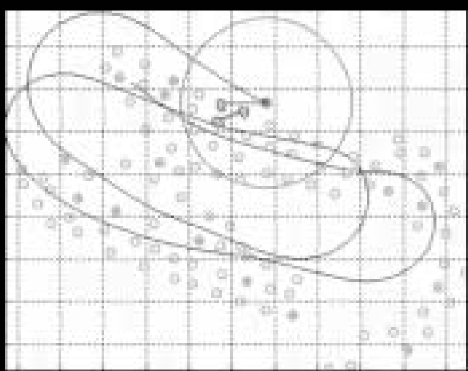
# INS/SLAM

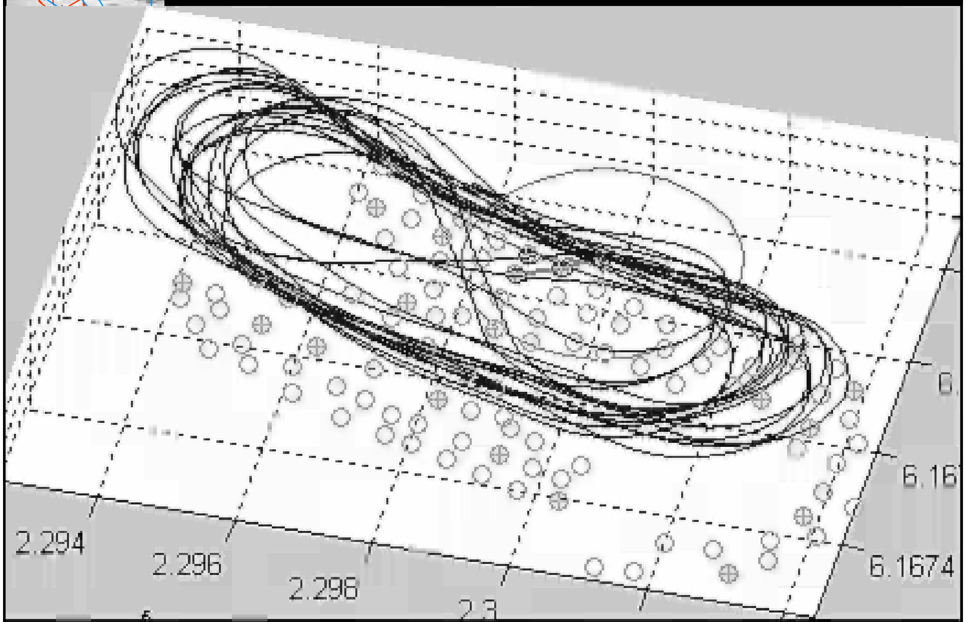
- Observation in Spherical vs. Cartesian coordinate

| Spherical | Cartesian |
|---|---|
| Non-linear observation model | Linear observation model |
| Un-correlated observation (range,bearing,elevation) | Correlated observation (x,y,z) |
| Suitable for single-platform tracking | Suitable for multi-platform tracking |



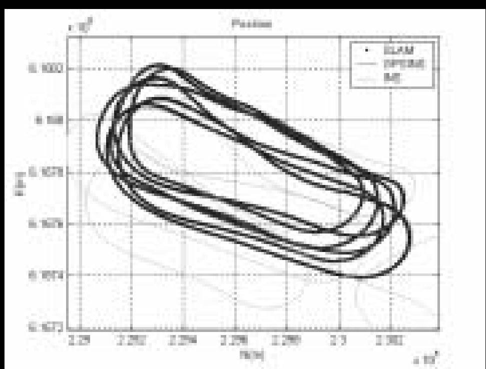


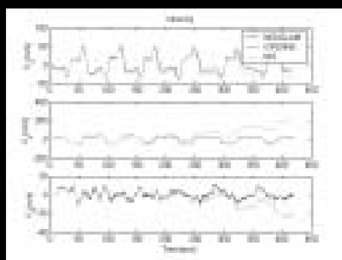



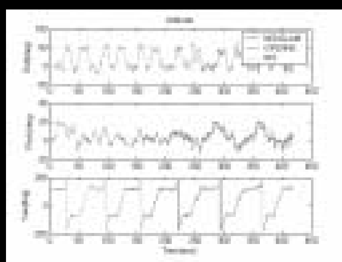




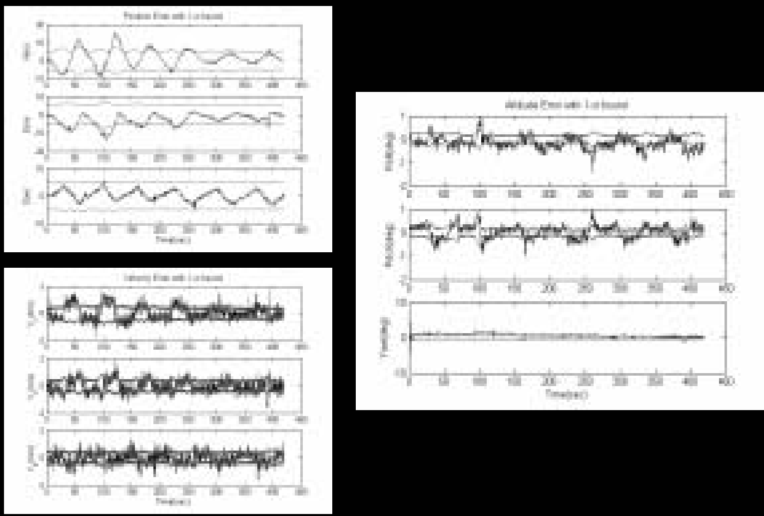

# INS/GPS vs. INS/SLAM







# Difference between INS/GPS and INS/SLAM



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# DDF SLAM

- Sharing of Map Information
- Mixture of State and Information forms

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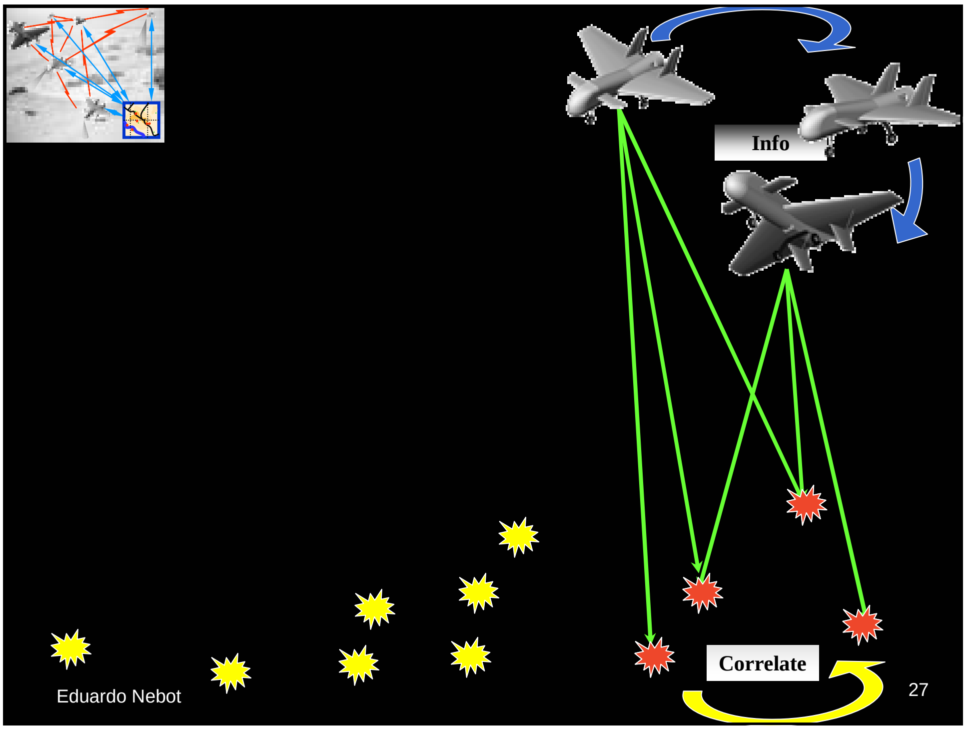
Info
Correlate
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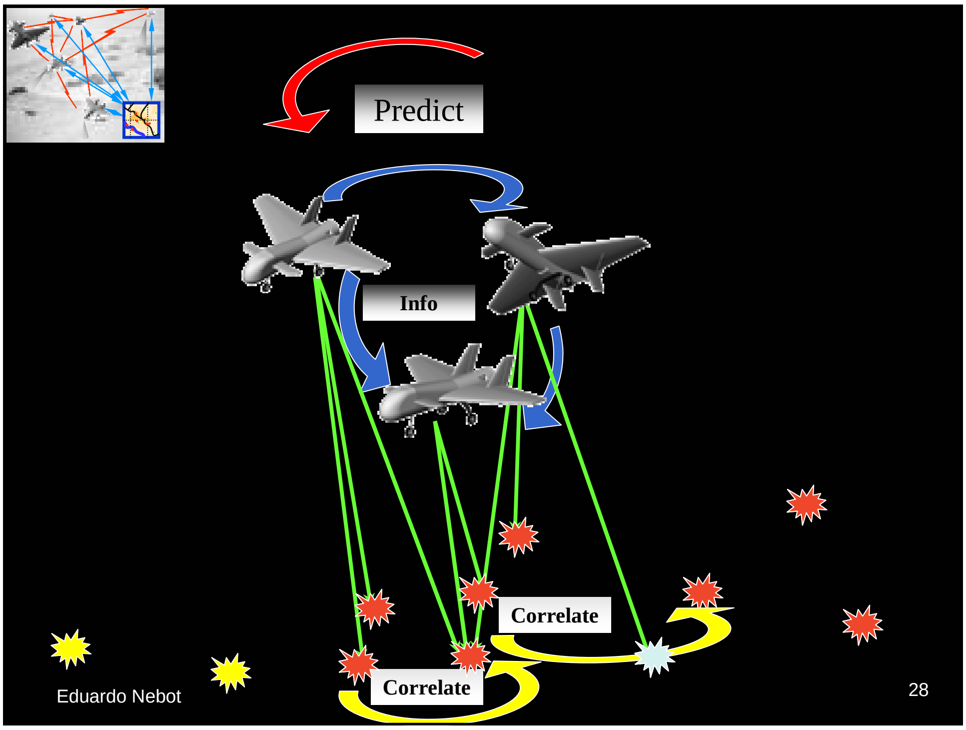
Predict
Info
Correlate
Correlate
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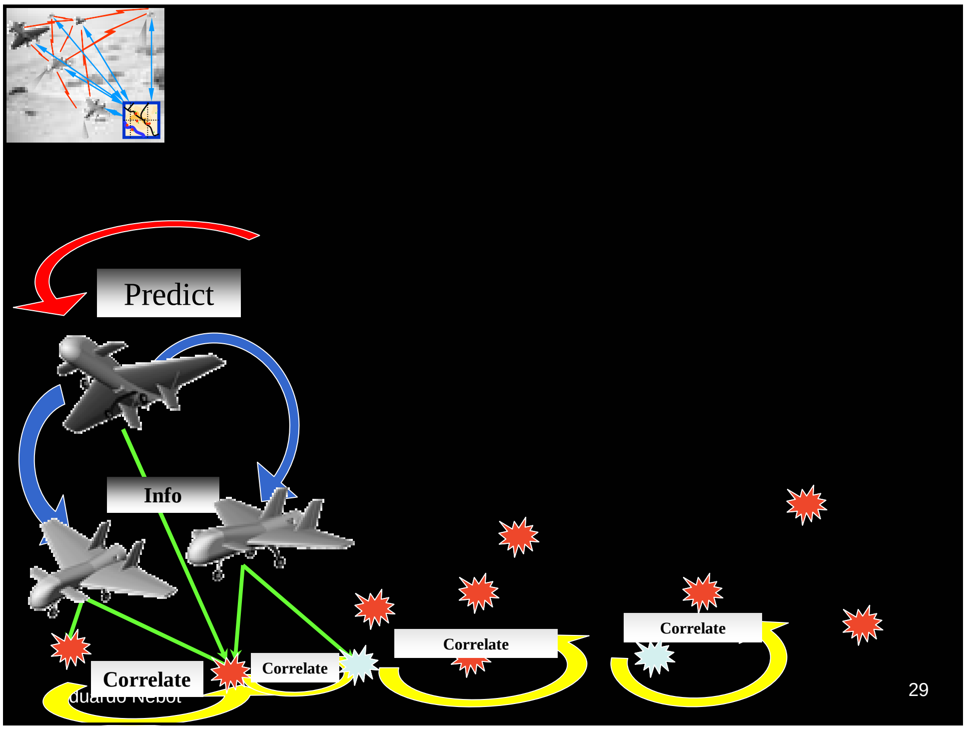
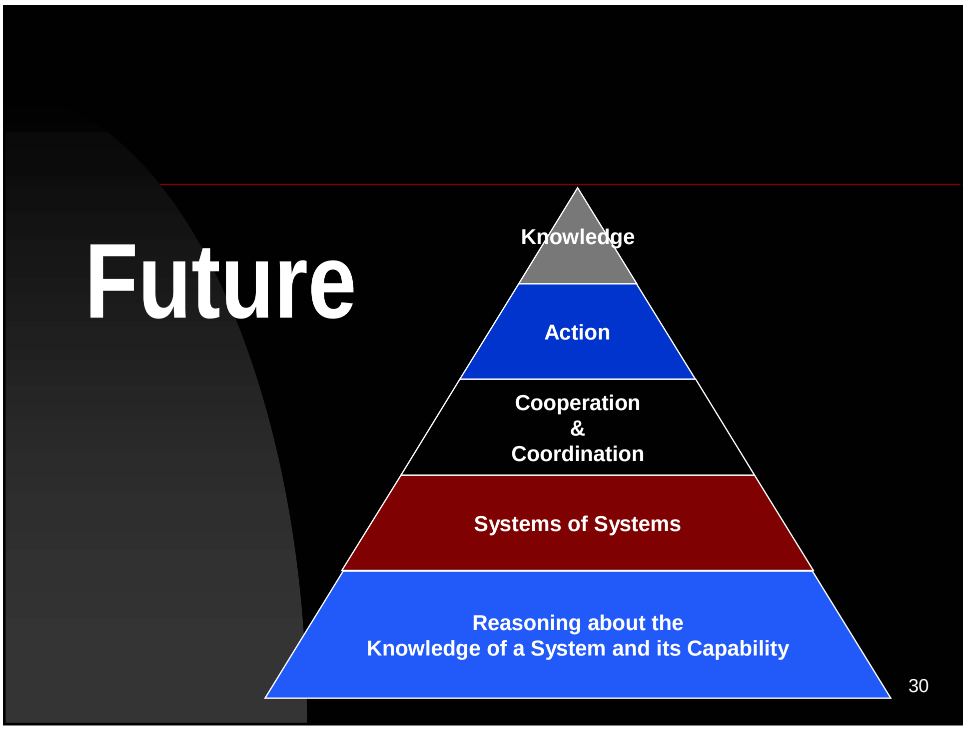

Predict
Info
Correlate
Correlate
Correlate
Correlate
29


Future
Knowledge
Action
Cooperation
&
Coordination
Systems of Systems
Reasoning about the
Knowledge of a System and its Capability
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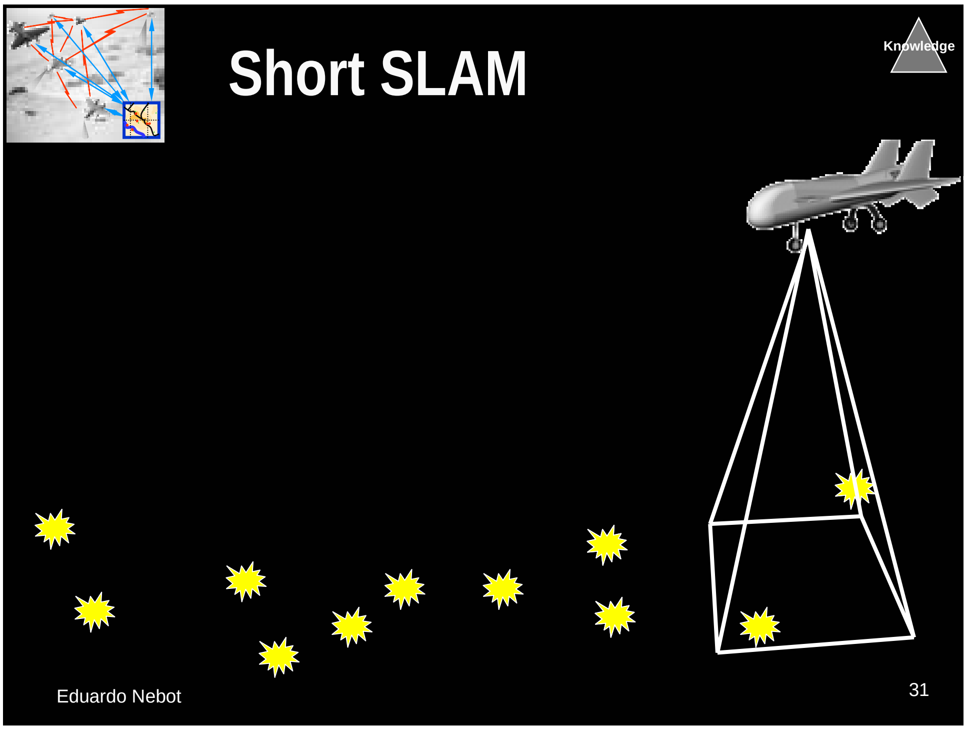

Short SLAM
Knowledge
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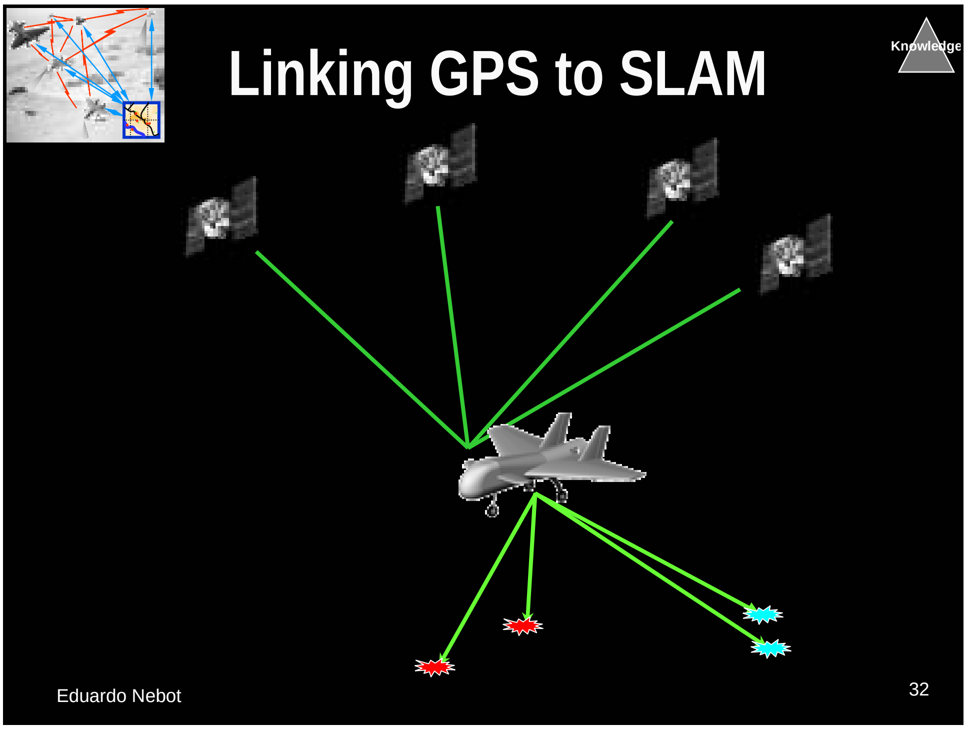

Linking GPS to SLAM
Knowledge
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# Autonomous SLAM

Knowledge
Action

- Need to assure integrity of navigation system is exceptional in order to close the loop
- Decision Time
  - Exploration or Exploitation
  - Future Horizon
  - Hybrid Control

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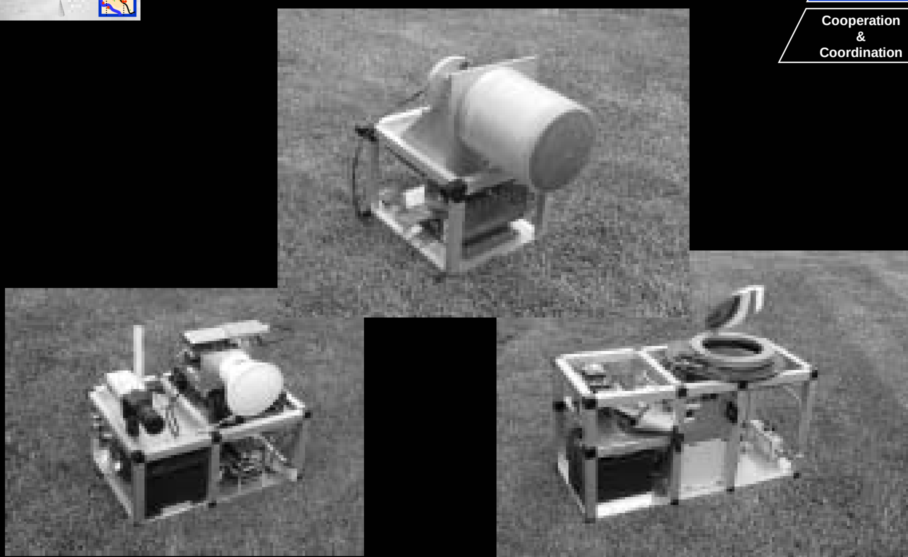
# Non-Gaussian Fusion and Control

Knowledge
Action
Cooperation & Coordination



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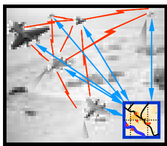
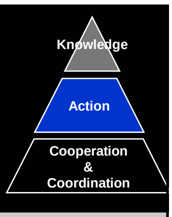
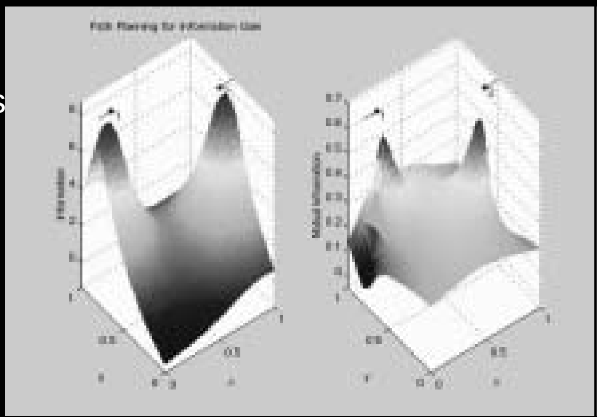


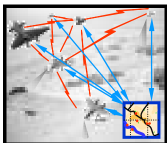
# Cooperative Platform Trajectory Generation



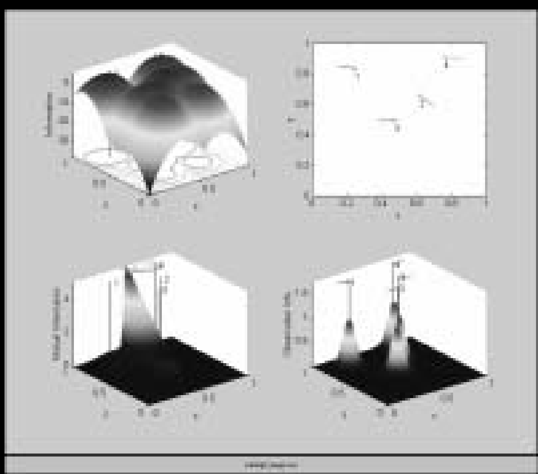

- Mutual information gain
  - Expected information gain is communicated
  - Local knowledge of global information
- Trajectory control localised based on maximising global utility

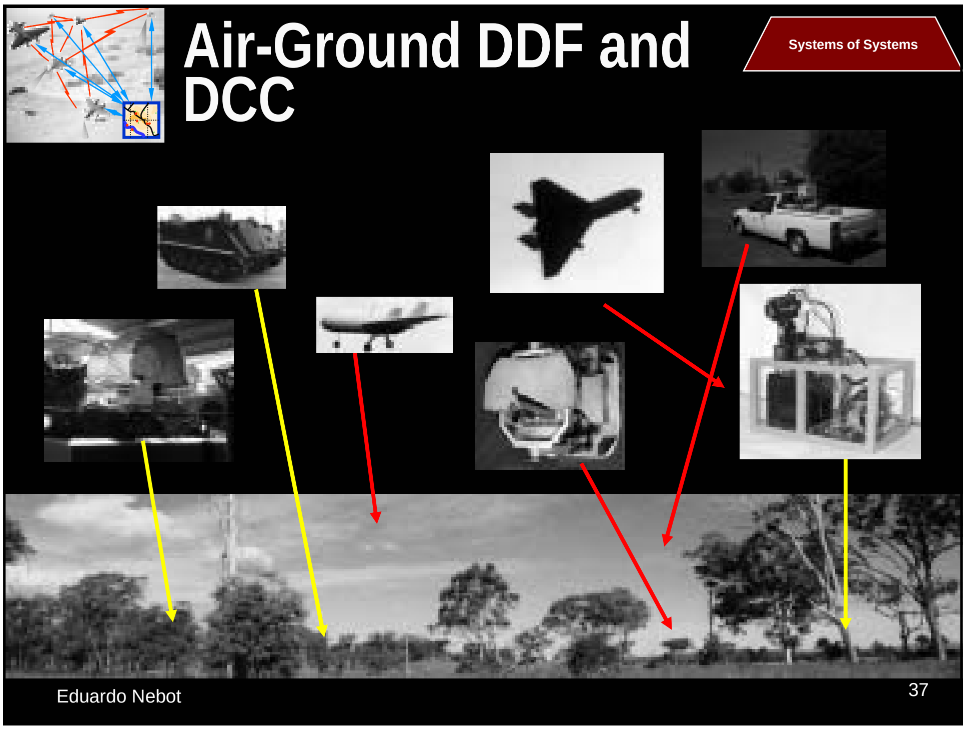






# Cooperative Platform Trajectory Generation


Air-Ground DDF and DCC
Systems of Systems
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