On-line Fusion of Functional Knowledge Within Distributed Sensor Networks

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Overview

- Introduction
- Research Issues 2008/2009
- Rule Exchange with Meta Knowledge
- Phase III
Objectives of the Project

Collaboration of intelligent systems (e.g., teams of robots, smart sensor networks, software agents) by exchanging classification rules

- How is the local environment observed?
- How does a node react on certain observations?
- Communication
- Learned rules (functional knowledge)
Proposed Classifier Approach – 1

- **Objective:** Classify multivariate observations \( \{x_i\} \)
- **Assumption:** Observations are generated by \( J \) stochastic processes
  - Observations form groups/clusters within the input space
  - Probabilistic modeling:

\[
p(c|x) = \sum_{j=1}^{J} p(c|j)p(j|x)
\]

where

\[
p(j|x) = \frac{p(x|j)p(j)}{p(x)}
\]
Proposed Classifier Approach – 2

Example: Modeling with Gaussian distributions:

\[ p(c|x) = \sum_{j=1}^{J} p(c|j) \frac{p(x|j)p(j)}{p(x)} \]

- Class distribution \( p(c|j) \): \( \mathcal{M}(c|\xi) \)
- Component densities \( p(x|j) \): \( \mathcal{N}(x|\mu_j, \Sigma_j) \)
- Mixing coefficients \( p(j) \): \( \mathcal{M}(j|\pi) \)
Proposed Classifier Approach – 3

Extraction of human readable classification rules:

- Prerequisite: Gaussians with diagonal covariance matrices
- Every component can be seen as classification rule

\[
\begin{align*}
&\text{if } x_1 \text{ is low and } x_2 \text{ is high then } c_1 = 0.91 \text{ and } c_2 = 0.09 \\
&\text{if } x_1 \text{ is high and } x_2 \text{ is high then } c_1 = 0.88 \text{ and } c_2 = 0.12 \\
&\text{if } x_1 \text{ is high and } x_2 \text{ is low then } c_1 = 0.95 \text{ and } c_2 = 0.05
\end{align*}
\]
Research Issues 2008/2009

- Classifier paradigm and training techniques:
  - Comparison to other functionally equivalent paradigms [FKSO09]
  - Comparison of generative and discriminative training methods [FS09]
  - Support for categorical input dimensions
  - Extension to time series classification [FGS09]

- Online training, knowledge exchange and knowledge fusion
  - Incremental learning
  - Improved novelty detection techniques [FJKS09]
  - Fusion of uncertain expert knowledge [AHS08] (best paper)
  - Knowledge exchange augmented by meta knowledge (i.e., information about knowledge) [FJKS09]

- Application studies
  - Intrusion detection: Aggregation of intrusion alerts [HS09]

- Collaboration with other groups
  - Study on evolvable hardware [GTG+08] (best paper)
  - Study on emergence in technical systems [MS08]
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Intention: Agents mutually exchange newly acquired knowledge (i.e., rules)

However, different agents rarely observe the exact same situation and use the same classifier

Not all received rules from other agents are really helpful!

▶ Inadequate rules may even deteriorate the decision boundary!
▶ Key question: Which rules should be integrated?
▶ Solution: Assess received rules with respect to different criteria (i.e., meta knowledge / interestingness)
Meta Knowledge of Rules – Usefulness

- Assessment if a rule is useful to classify local observations
  - Rule stored in a cache and rated over time
  - Useful, if a sufficient amount of samples can be assigned to the rule
Meta Knowledge of Rules – Informativeness

- A received rule is considered informative if it describes a **really new** kind of data-generating process
  - The more distant a new rule is with respect to the existing rules, the more confident we are that there really is a new process
Meta Knowledge of Rules – Uniqueness

- Assessment of a rule’s conclusion $p(c|j)$
  - Measures how distinct the conclusion is
  - Evaluates the difference between the largest and the second largest class probability value
Meta Knowledge of Rules – Importance

- Assessment of the sender’s mixing coefficient $p(j')$ of the received rule $j'$
  - Very important if $p(j')$ is far above the average mixing coefficient $\frac{1}{J}$ of the sender
  - $J$: Total number of rules in the sender’s classifier
Phase III
Phase III – 1

Fusion of parameter estimates

- Parameter estimates of rules based on observed data
- Uncertainty regarding the parameter estimates explicitly modeled with second order probabilities (i.e., distributions over parameters)
  - Rule premises
  - Rule conclusions
- Agents exchange distributions over parameters
  - Must be fused
Phase III – 2

Provision of an OC-Toolbox for self-reflection and self-adaptation techniques

- **Self-Reflection**: Ability of an organic system to recognize on its own
  - The emergence of a new sample-generating process (i.e., the need for new knowledge)
  - The termination of an existing sample-generating process (i.e., the obsoleteness of knowledge)

- **Self-Adaptation**: Ability to (semi-)autonomously react on detected changes in the environment
  - Create new rules for new processes (premises learnt unsupervised, conclusions provided by human experts, for instance)
  - Remove existing but obsolete rules from the classifier
Phase III – 3

Application Scenarios:
- Driver assistance systems
- Distributed intrusion detection systems
List of Publications


Thanks a bunch for your attention!

More information: http://www.cis-research.de