# ISIS: An Explicit Model of Teamwork at RoboCup–97

ISIS (ISI synthetic) won the third-place prize in the RoboCup-97 Simulation League tournament. ISIS was also the top U.S. team. Although ISIS's performance in the tournament was initially marked by lopsided wins, its later games were exciting and close; it twice won in overtime. In terms of research accomplishments, ISIS illustrated the reuse of STEAM, a general model of teamwork (Tambe 1997), that both reduced its development time and improved teamwork flexibility.

ISIS's development was driven by the three research challenges emphasized by the RoboCup simulation league: (1) teamwork, (2) multiagent learning, and (3) agent and team modeling. With respect to teamwork, our previous work was based on the development of pilot-agent teams for real-world combat simulations. For this work, providing individual agents with preplanned, domain-specific coordination knowledge led to teamwork inflexibility. Furthermore, the coordination knowledge was not reusable. STEAM, a general, explicit model of teamwork, was developed to alleviate these difficulties. STEAM requires that individual team members explicitly represent its team's goals, plans, and mutual beliefs. It then enables team members to autonomously reason about coordination and communication in teamwork, providing improved flexibility. Given its domain independence, it also enables reuse across domains—here, RoboCup provided a challenging test domain given its substantial dissimilarity to the original domain. However, a promising 35 percent of STEAM code was reused for RoboCup. Indeed, all the current communication among ISIS agents is driven by STEAM's general-purpose reasoning about teamwork. For example, midfielders communicate with each other about an approaching threat so they can coordinate their defense. With possible improvement in STEAM reuse in the future, such coordination might improve as well.

ISIS also took initial steps toward addressing the challenge of multiagent learning. Using C4.5, ISIS players learned offline to choose an intelligent kicking direction, avoiding areas of concentration for opponent players. Further aspects of multiagent learning, as well as arenas of agent and team modeling (particularly to recognize opponents' strategies), are under active investigation.

ISIS agents were developed as a two-level architecture: The lower level, developed in C, processes input and rapidly computes recommendations for directions to turn (to intercept the ball) or possible directions to kick the ball (for example, kicking direction computed by C4.5 rules mentioned previously or kicking direction to clear the ball). However, the lower level does not make any decisions. Instead, all the decision making rests with the higher level, implemented in the SOAR integrated AI architecture, which takes into account the recommendations made by the lower level. STEAM's teamwork reasoning is currently also implemented in SOAR and has led to enhancements to the SOAR architecture. For example, explicit team operators, an enhancement of SOAR's individual operators, are used for explicit representation of a team's goal and plans.

Some key weaknesses of ISIS players stemmed from a somewhat inappropriate interaction with the RoboCup simulator: The simulator version used in RoboCup-97 allowed agents to take as many as 3 actions (1 action every 100 milliseconds [ms]) before sending them a sensor update (1 update every 300 ms). This action-to-sensor update ratio required that agents continually make predictions. Unfortunately, with weak predictive capabilities, ISIS agents could not always quickly locate and intercept the ball or maintain awareness of positions of teammates and opponents. However, the RoboCup simulator will evolve for RoboCup-98 toward more humanlike play.

We hope to continue working on ISIS in preparation for RoboCup-98 and meet the research challenges outlined for the simulation league. More information about ISIS, including the code, is available at www.isi.edu/soar/tambe/socteam.html.

*– Milind Tambe, Jafar Adibi, Yaser Al-Onaizan, Ali Erdem, Gal A. Kaminka, Stacy C. Marsella, Ion Muslea, and Marcello Tallis*

**Group A:** LAI (Université Carlos III De Madrid), FC MELLON (CMU), RM KNIGHTS (RMIT), ICHIMURA (Kinki University, Japan).

**Group B:** RIEKKI (University of Oulu, Finland), CMUNITED (CMU), HEADLESS CHICKENS (RMIT), NIT-STONES (Nagoya Institute of Technology, Japan).

**Group C:** MICROB (Université de Paris VI), BALCH (Georgia Institute of Technology), PROJECT MAGI (Aoyama University, Japan), OHTA (Tokyo Institute of Technology, Japan).

**Group D:** AT HUMBOLDT (Humboldt University, Germany), TEAM SICILY (Stanford University), KASUGA-BITO (Chubu University, Japan), ANDHILL (Tokyo Institute of Technology, Japan).

**Group E:** PAGELLO (University of Padua, Italy), HAARLEM (Chukyo University, Japan), ORIENT (Toyo University, Japan).

**Group F:** UBC DYNAMO (University of British Columbia, Canada), LUKE (University of Maryland), OGALETS (University of Tokyo, Japan), TUT (Toyohashi University of Technology, Japan).

**Group G:** CHRISTENSEN (Charlmers University of Technology, Sweden), TEAM GAMMA (ETL, Japan), KOSUE (Kinki University, Japan).

**Group H:** ISIS (USC-ISI), GARBAGE COLLECTORS (private, Japan), I&W (Waseda University, Japan).

*Table 3. RoboCup-97 Team List.*