My Ties to Logical Methods in CS

COMPUTATIONAL LOGIC

Hyper-Resolution Theorem Prover

VERIFICATION

LCF Prover

LCF Prover

jMocha Model Checker

NSF-Career Hybrid Systems

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Emergent Behavior in Cardiac Cells

- Global qualitatively novel system behavior

- Results from interaction among system components

- Ceases to exist when specific components are removed

- Afflicts more than 3 million Americans alone
Research Challenges

- Gr1: How to formally specify emergent behavior?
- Gr2: How to efficiently predict or detect its onset?
Nonlinear Hybrid Automaton Switched Differential Equations

\[ \begin{align*}
\dot{u} &= e + (u - \theta_v)(u_{\text{u}} - u)v g_{fi} + ws g_{si} - g_{so}(u) \\
\dot{v} &= -v g_{v} \\
\dot{w} &= -w g_{w} \\
\dot{s} &= S^+(u,k_s,u_s,0,1) g_{s2} - s g_{s2}
\end{align*} \]

Heaviside Function

PDEs are simulated as Finite Difference Equations

2D/3D Description Partial Differential Equations

\[ \frac{\partial u}{\partial t} = \nabla(D \nabla u) + R \]

Diffusion e Reaction u,v,w,s
Radu Grosu

Specification and Prediction of Emergent Behavior
Specification of Emergent Behavior
Syntax inspired by linear temporal logic ($\mathcal{LTL}$)

$$\varphi := p \mid \neg \varphi \mid \varphi_1 \lor \varphi_2 \mid X \varphi \mid \varphi_1 U \varphi_2$$

Challenges of this project

- Define appropriate atomic propositions
- Define appropriate spatial-temporal operators
- Investigate the expressive power of the logic
Spatial-ZoomIn Logic
(HSCC’08, CACM’09)

- Atomic Proposition $P(C = y) \geq \theta$: Density of yellow color $\geq \theta$
- Spatial operator $\chi \varphi$: Property $\varphi$ holds after zooming in once

Space reduced to a path of normalized densities. No time
Spatial-Temporal Logics Around

Spatial Logics

- Topological: $S_{4u}$, $RC_{max}$, $RCC-8$, $BRCC-8$, $RC$

$$\tau := p \mid \bar{\tau} \mid \tau_1 \cup \tau_2 \mid I\tau \mid C\tau$$

$$\varphi := \tau_1 \subseteq \tau_2 \mid \neg \varphi \mid \varphi_1 \lor \varphi_2$$

- Metric: $MS$, $MS_{\geq, <}$, $MS_{\leq, <}$

$$\tau := p \mid \{l\} \mid \bar{\tau} \mid \tau_1 \cap \tau_2 \mid \exists^=a\tau \mid \exists^<a\tau \mid \exists^{>a}\tau \mid \exists_{>a}\tau$$

- Metric-Topological: $MT$, $CSL$, $CMS$

$$\tau := p \mid \bar{\tau} \mid \tau_1 \cap \tau_2 \mid \exists^{\leq a}\tau \mid \exists^{< a}\tau \mid \exists^{>a}\tau \mid I\tau \mid C\tau$$

Temporal Logics

- Linear time: $LTL$

- Branching time: $BTL$ $E\varphi$, $A\varphi$

Spatial Logics + Temporal Logics = ?

- $S_{4u} + LTL$, $LTL_{\Box}[RC]_{tt}$

Radu Grosu
Gr1 (p. 92): Specification of Emergent Behavior
Prediction of Emergent Behavior
Prediction of Emergent Behavior

Model

\[ \frac{\partial u}{\partial t} = \nabla (D \nabla u) + R \]

Spatial-temporal logical formula

\[ \phi := p \mid \neg \phi \mid \phi_1 \lor \phi_2 \mid \exists \phi \mid \phi_1 \mathcal{U} \phi_2 \]

Challenges of this project

- Develop symbolic verification techniques
- Develop statistical verification techniques
- Develop multiscale abstraction techniques
Spatial-ZoomIn Logic
(HSCC’08, CACM’09)

Preprocessing
User-selected paths

Set of Records
Spiral
Not Spiral
Spiral

Training
Classification
WEKA Decision Tree

Testing

Continuous Behavior
Simulation
Discrete Behavior

User selects paths to spiral core

QuadTrees

Add counter example
Retraining

Bounded Model Checking

LSL Formula

Translator to LSL Formula

SMT Solver

Radu Grosu
Gr2 (p. 93) : Prediction of Emergent Behavior
Collaboration

Gr1: Specification of EB

- Local collaboration
  • Agatha Ciabatoni
  • Helmut Veith

- External collaboration
  • Flavio Fenton (GTech)
  • Scott Smolka (SBU)
  • Patrick Cousot (NYU)

Gr2: Prediction of EB

- Local collaboration
  • Roderick Bloem
  • Armin Biere

- External collaboration
  • Ed Clarke (CMU)
  • Andreas Podelski (UF)
  • Oded Maler (Verimag)
Curvature Analysis
(CMSB’11, TCBB’12)

- Atomic Propositions: Curvature along the front of the wave
- Temporal operators: As in linear (signal) temporal logic

Space reduced to a line (of curvatures). Linear time.
Time-Frequency Logic
(ATVA’12)

- Atomic Prop: $\theta$-amplitude
- Time: $\mathcal{X} \phi$, $\phi_1 U \phi_2$
- Frequency: $\mathcal{X} \phi$, $\phi_1 U \phi_2$

Time: As in LTL
Frequency: As in LTL