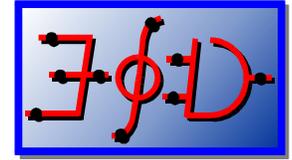


**BMAS 2005**

**VHDL-AMS based genetic optimization of  
a fuzzy logic controller for  
automotive active suspension systems**

**Leran Wang and Tom Kazmierski**  
**{lw04r,tjk}@ecs.soton.ac.uk**

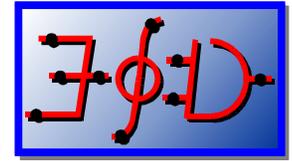




## Outline

- **Introduction and system model**
- **Shape optimization of fuzzy logic membership functions**
- **Integrated GA optimiser in VHDL-AMS testbench implemented as a state machine**
- **Experimental results**
- **Conclusion**

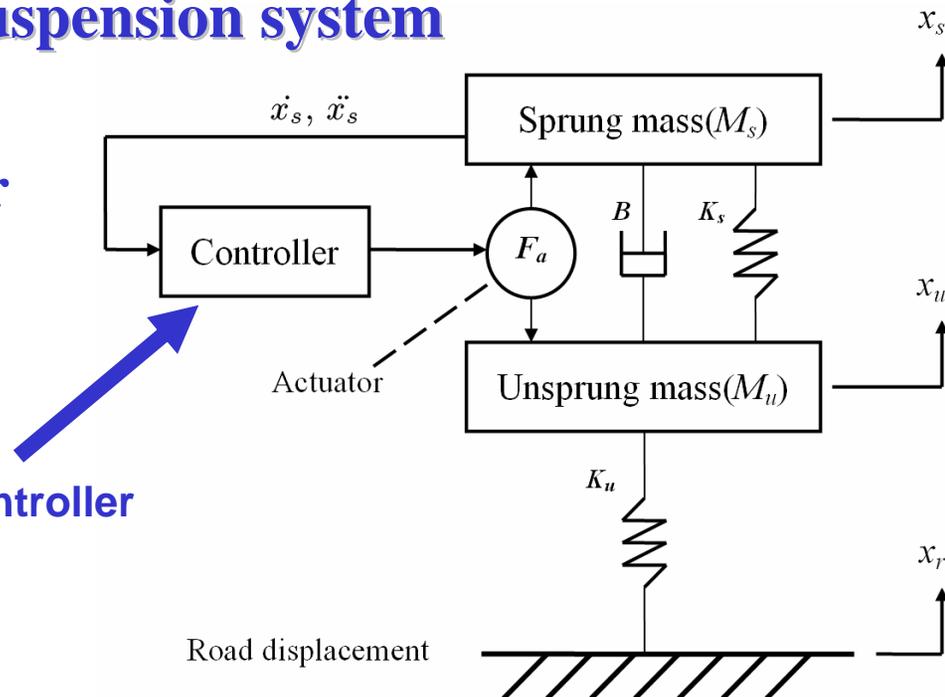


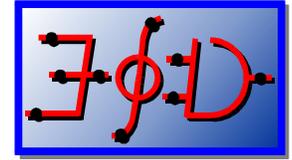


## Introduction and system model

- VHDL-AMS recommended by a European automotive consortium as a unified automotive modeling language
- Automotive active suspension system
  - Active suspension
  - Actuator controller

Fuzzy logic controller

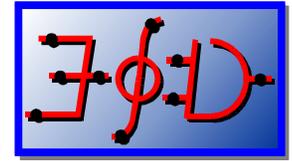




## Fuzzy logic controller (FLC)

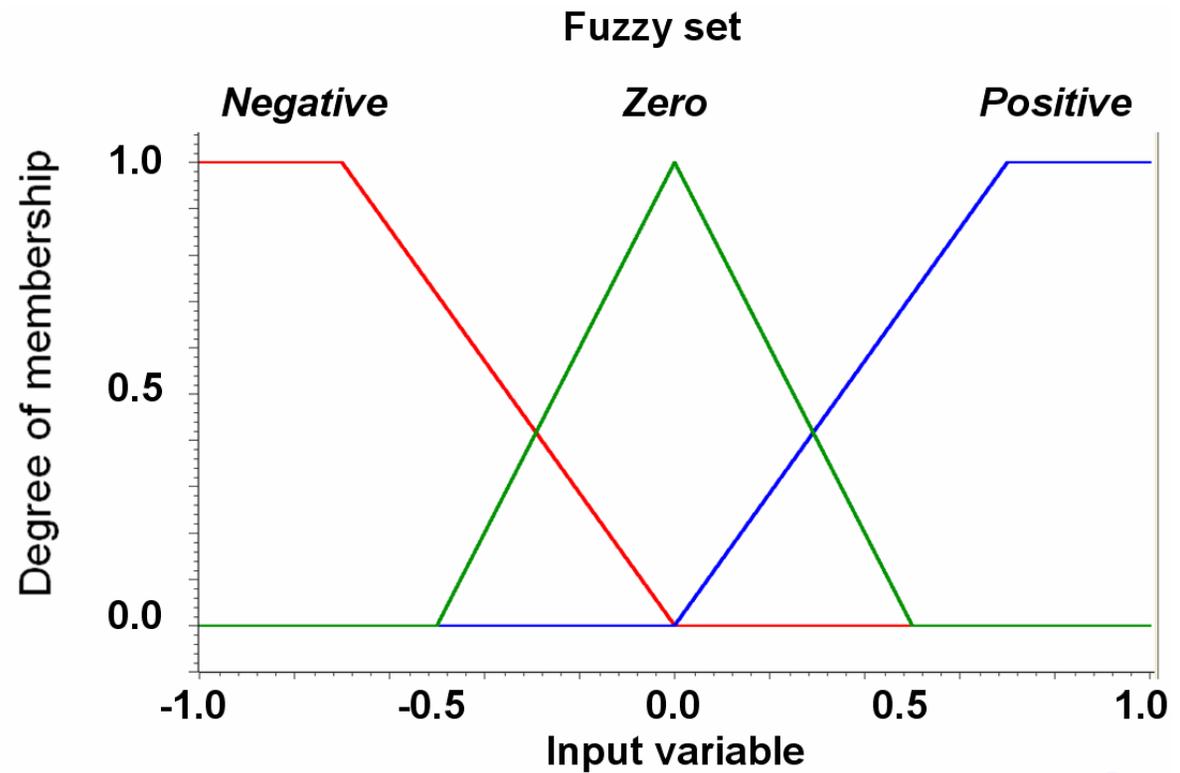
- Based on the general principles of fuzzy set theory (L. Zadeh, 1965)
- Input and output variables are similar to a conventional controller
- Handling uncertain and complex systems, e.g. active suspension system

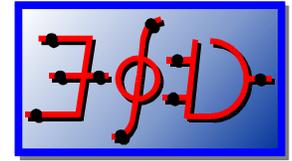




# Fuzzy logic controller (FLC)

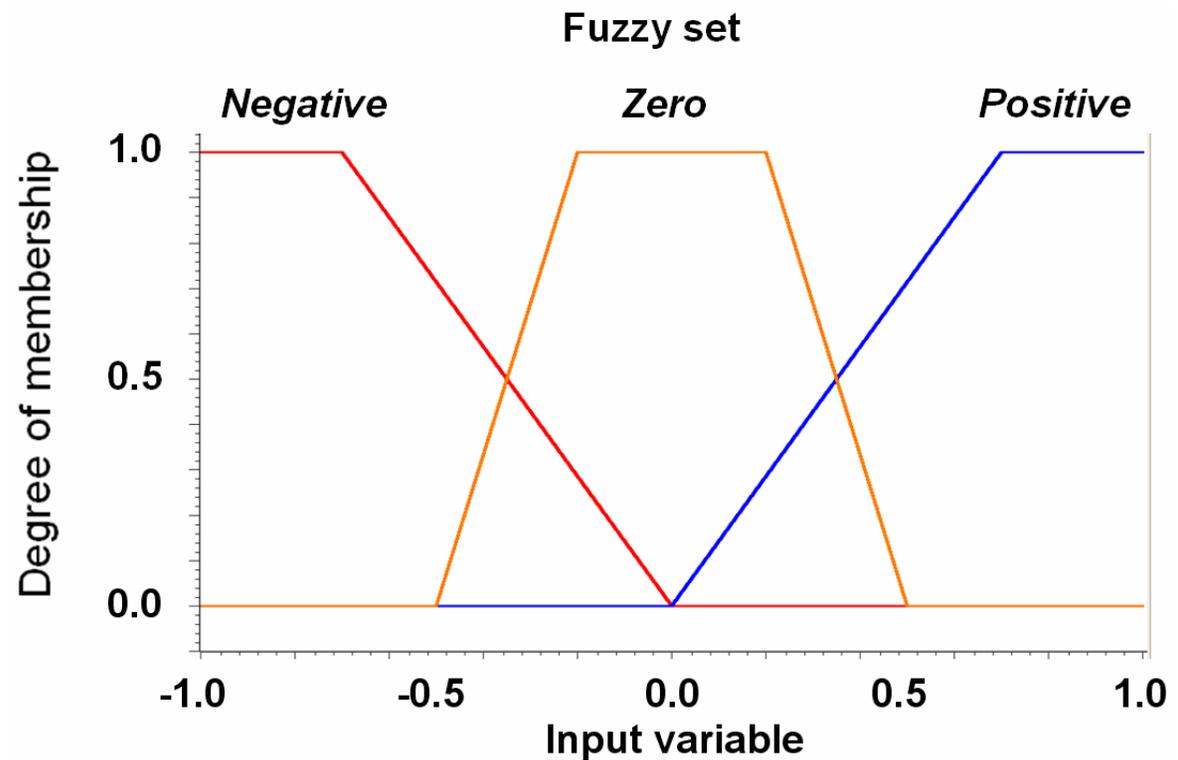
- Regular membership functions
  - Triangular

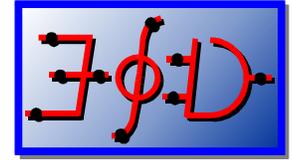




## Fuzzy logic controller (FLC)

- Regular membership functions
  - Trapezoidal

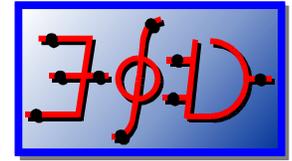




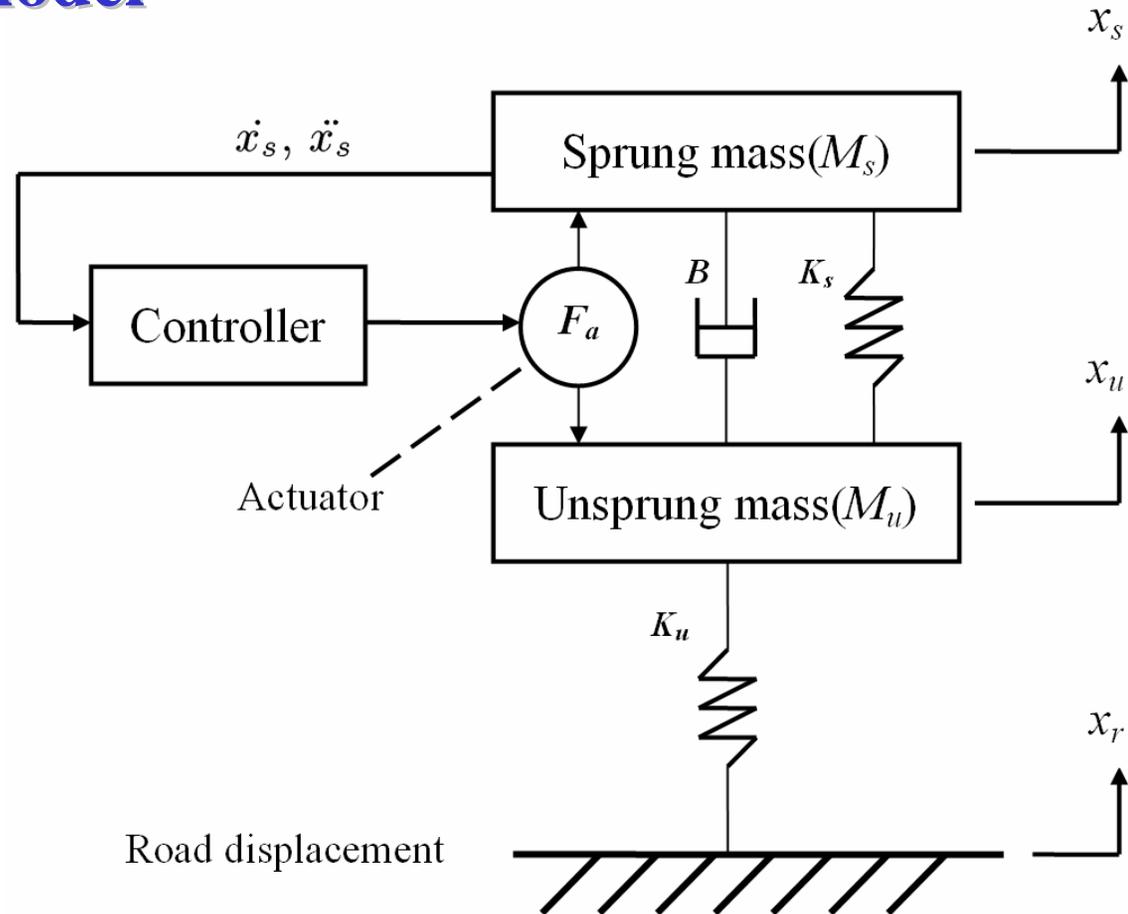
## Genetic algorithm (GA)

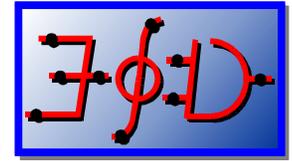
- **Optimization method based on natural selection (D. Goldberg, 1989)**
- **A GA usually has the following elements**
  - Population of chromosomes
  - Selection according to fitness
  - Crossover to produce new offspring
  - Random mutation of new offspring



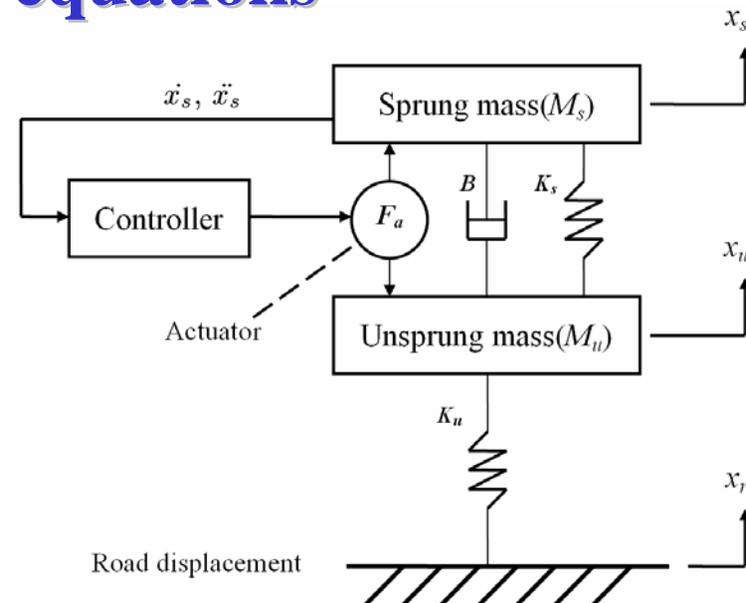


# Active suspension model





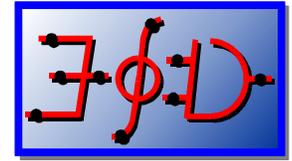
## Sprung and unsprung mass equations



$$\ddot{x}_s M_s = K_s(x_u - x_s) + B(\dot{x}_u - \dot{x}_s) + F_a$$

$$\ddot{x}_u M_u = -K_s(x_u - x_s) - B(\dot{x}_u - \dot{x}_s) + K_u(x_r - x_u) - F_a$$



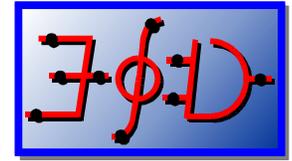


# FLC

- **Inputs: sprung mass velocity and acceleration**
- **Output: actuator force**
- **Three linguistic variables: *Positive (P)*, *Zero (Z)* and *Negative (N)***
- **Fuzzy rules set**
- **Max-product inference**
- **Center of gravity defuzzification**

		Acceleration		
		P	Z	N
Velocity	P	N	N	Z
	Z	N	Z	P
	N	Z	P	P



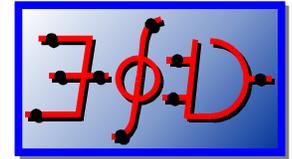


## Shape optimization of fuzzy logic membership functions

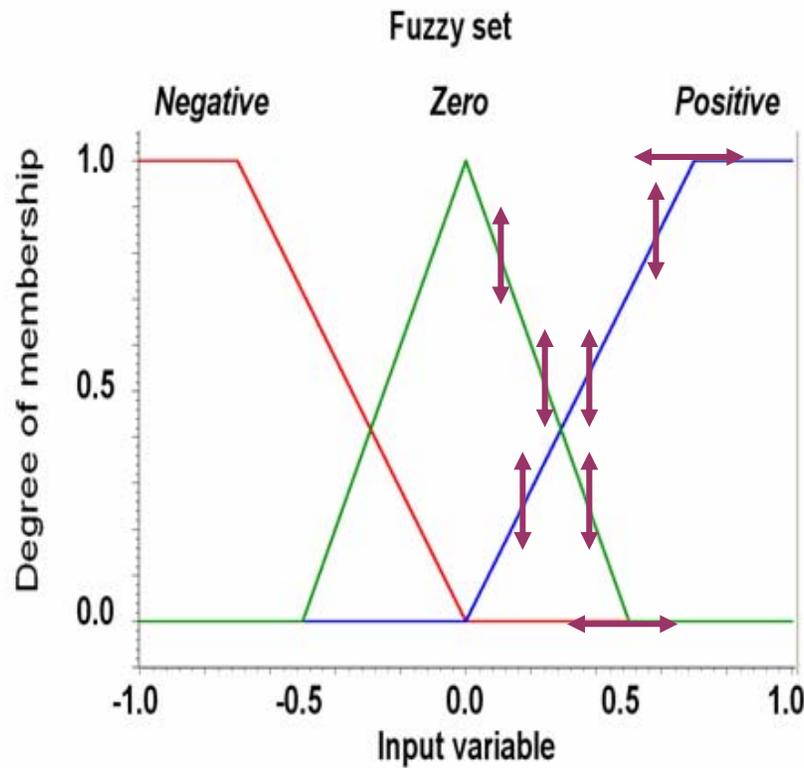
### •Fuzzy logic membership function

- Graphical representation of input's degree of participation in a fuzzy set
- Shapes may affect FLC performance (A. Barr and J. Ray, 1996)
- Shape optimization using a GA

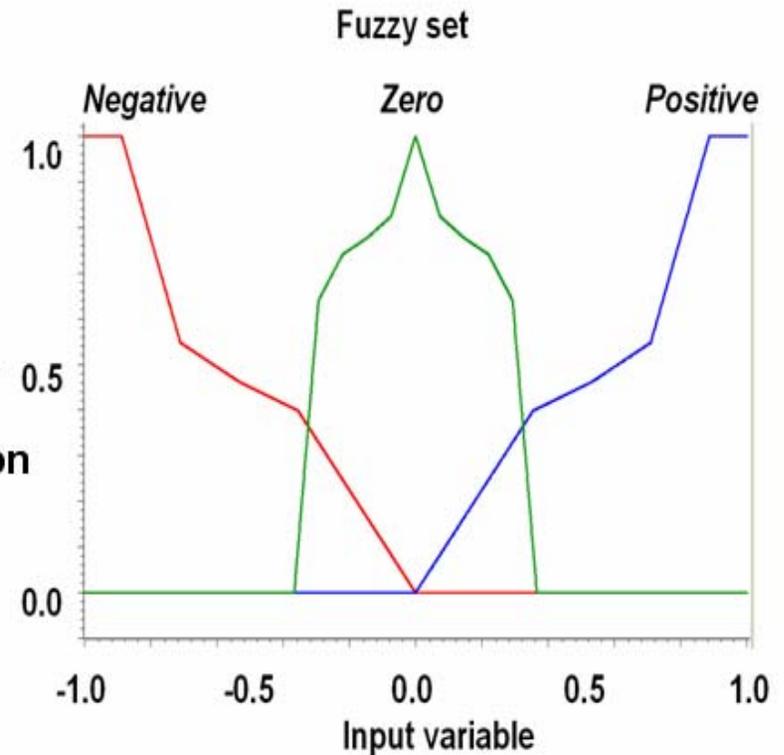


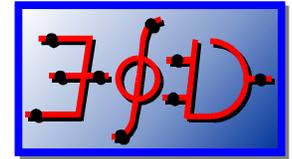


# Shape optimization of fuzzy logic membership functions



GA Optimization



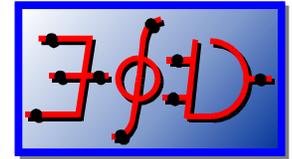


## Integrated GA optimizer in VHDL-AMS testbench

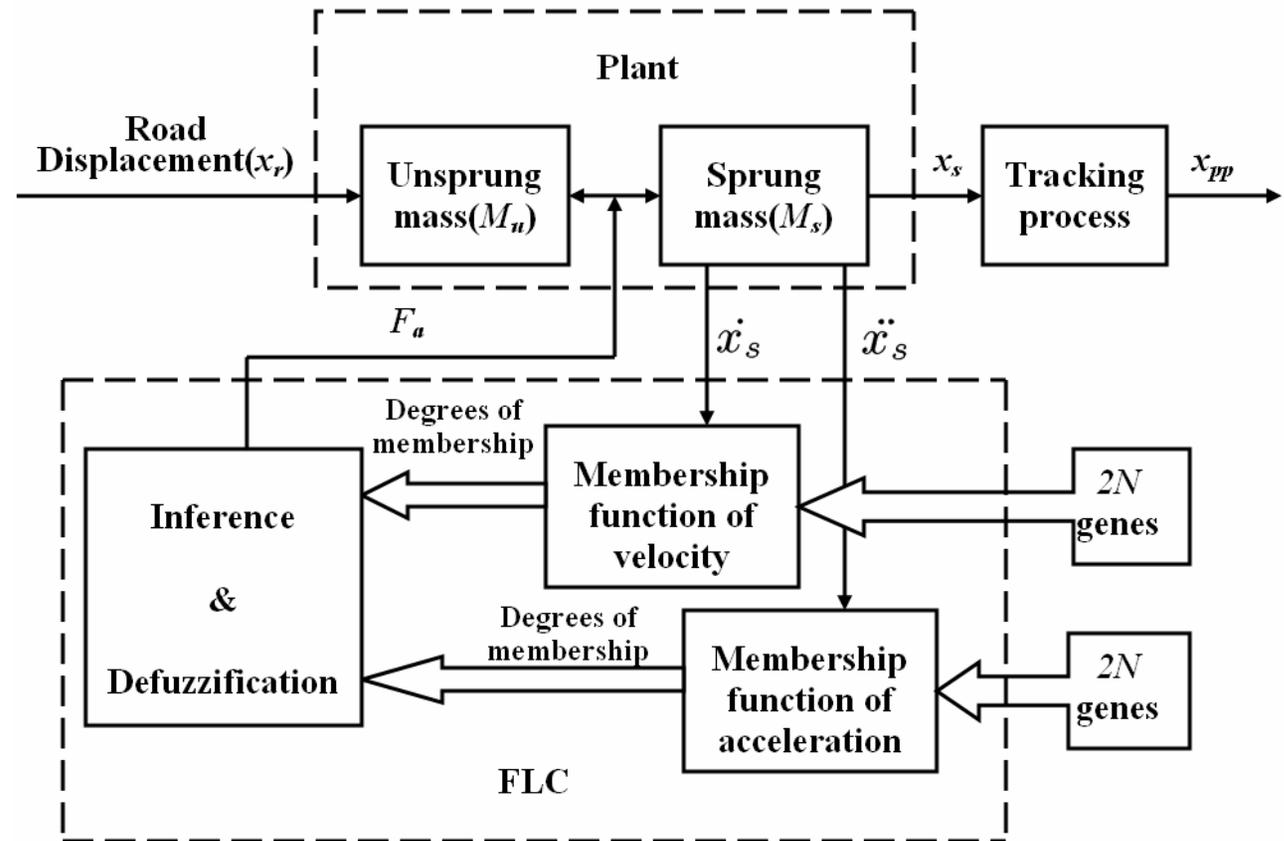
• **Integrated hardware system performance optimizer wholly implemented in VHDL-AMS**

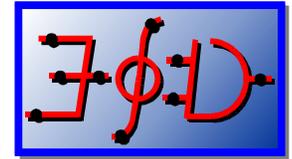
- Active suspension system
- FLC
- GA optimization



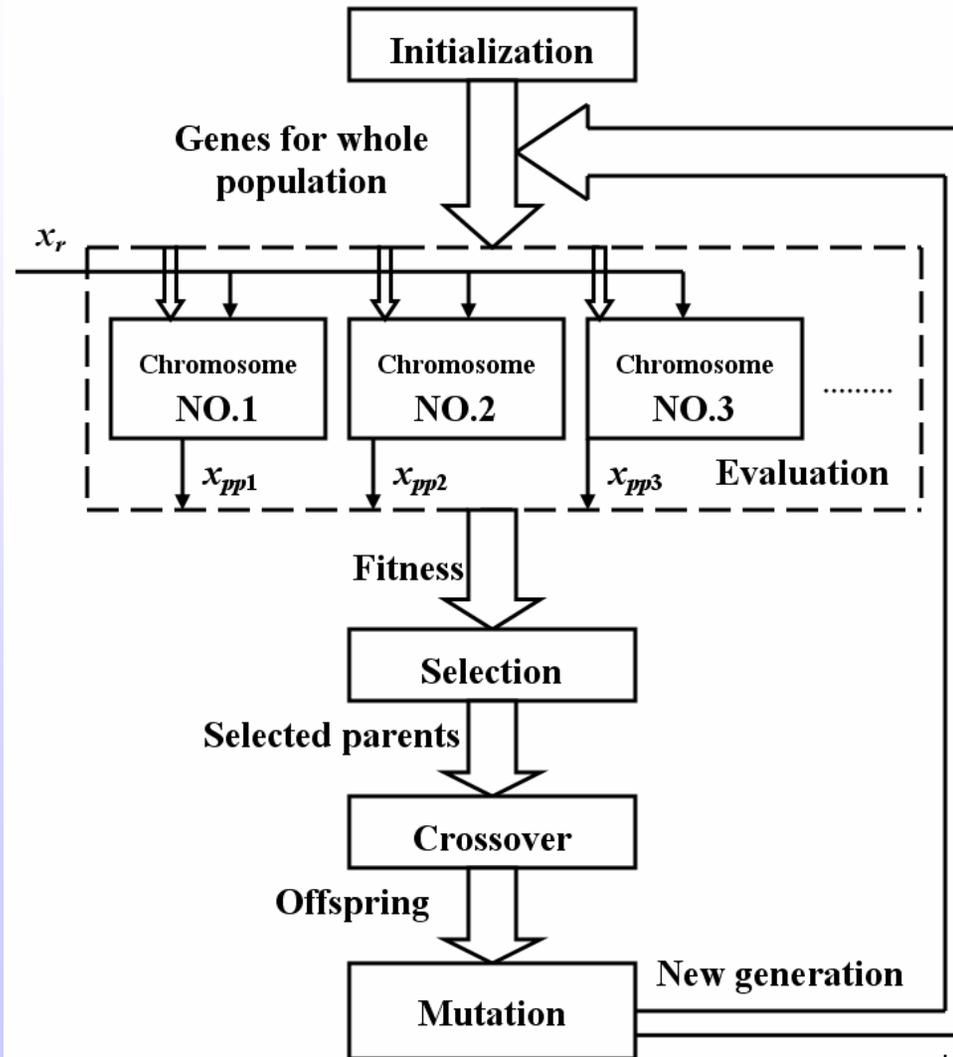


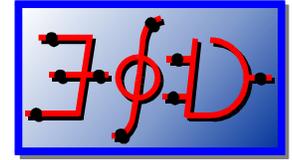
## Block diagram of one chromosome (VHDL-AMS entity)





# Flow chart of a parallel GA

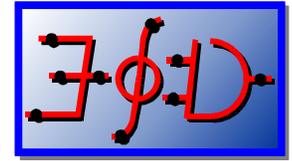




## GA features:

- Evaluation – using peak-to-peak value of  $x_s(t)$  as fitness
- Tournament selection – chromosomes with small  $x_{pp}$  are more likely to be selected to produce offspring
- Elitism – artificially inserting the best solution into each new generation
- Arithmetic crossover – generate new offspring for real number genes
- Gene mutation – introduce new solutions into the next population
- VHDL-AMS finite state machine controls the optimizer

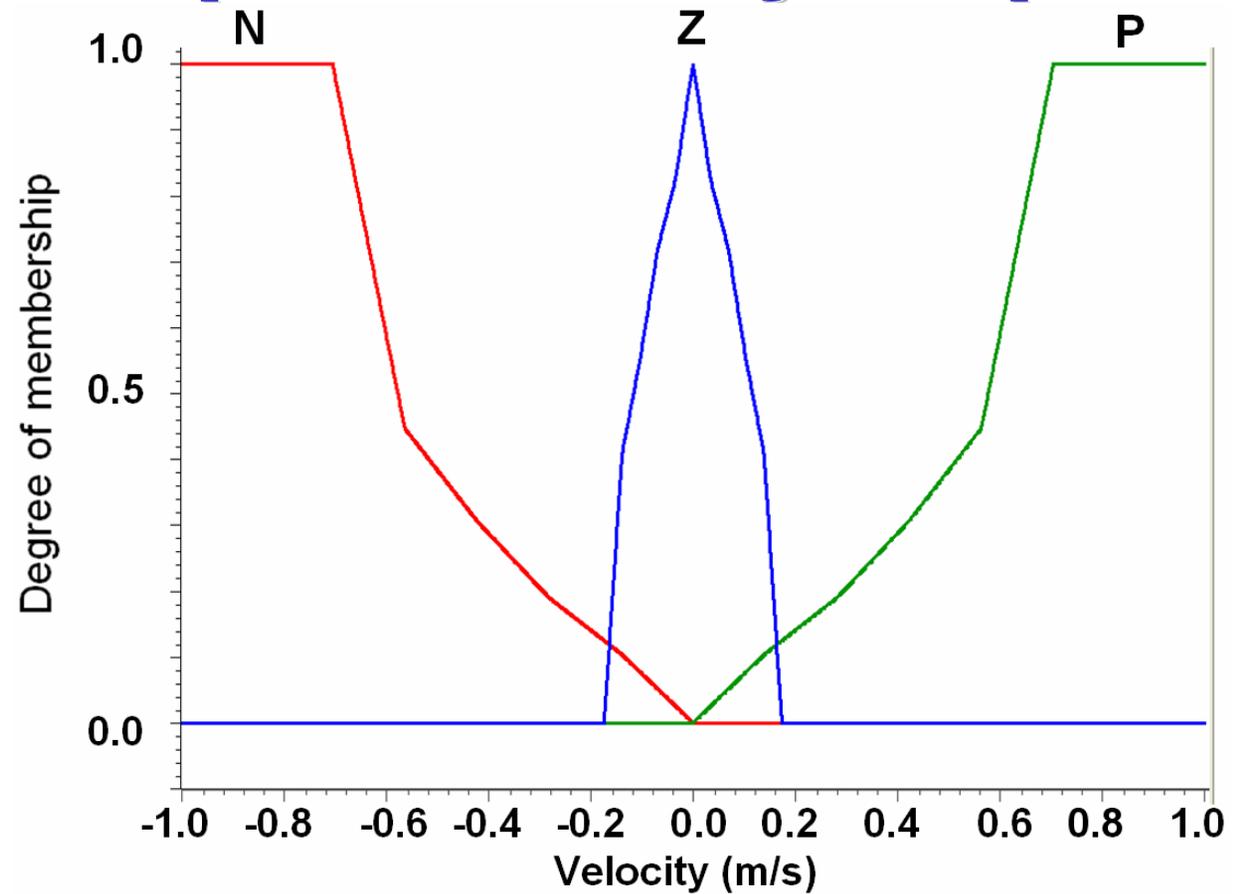


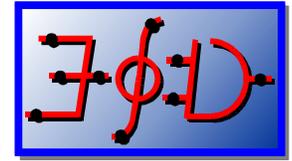


## Experimental results

- GA optimized membership functions with irregular shapes

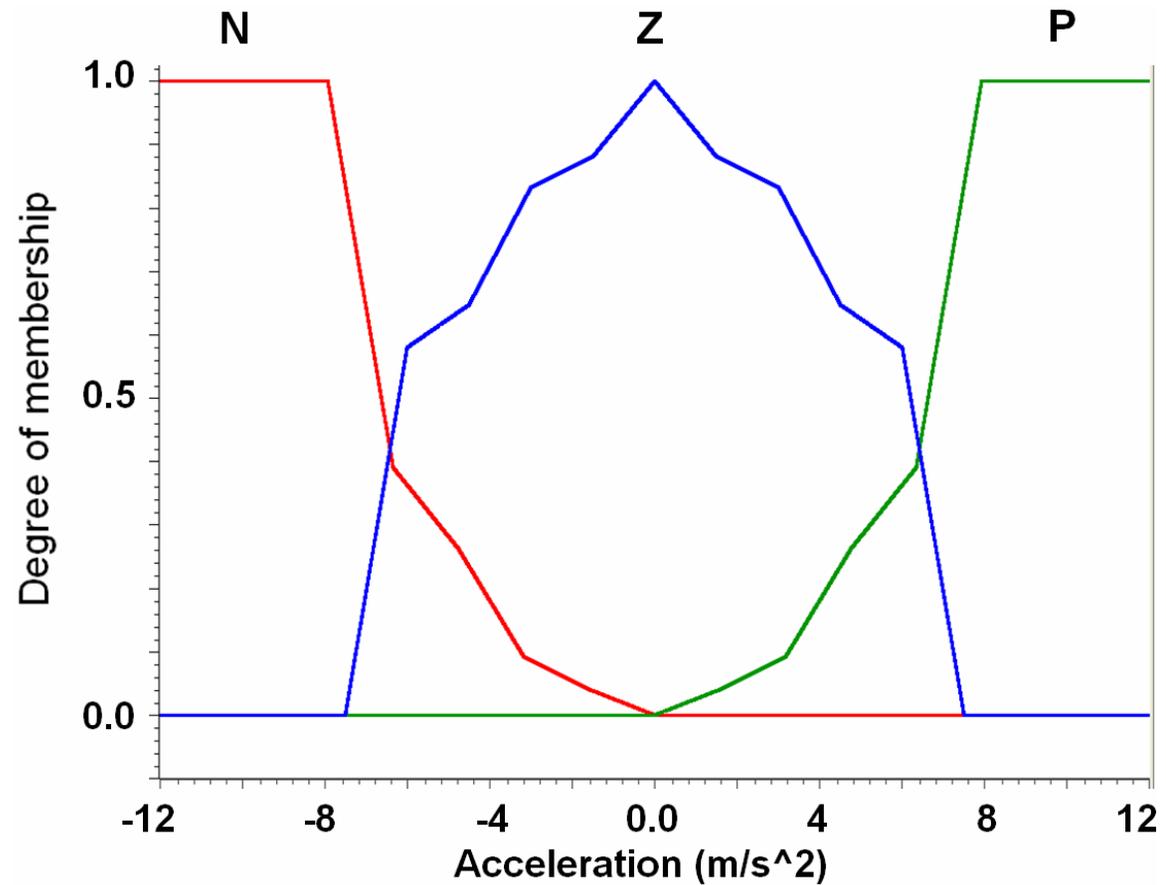
- Velocity

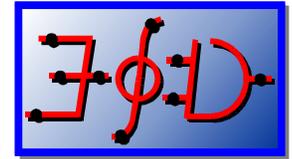




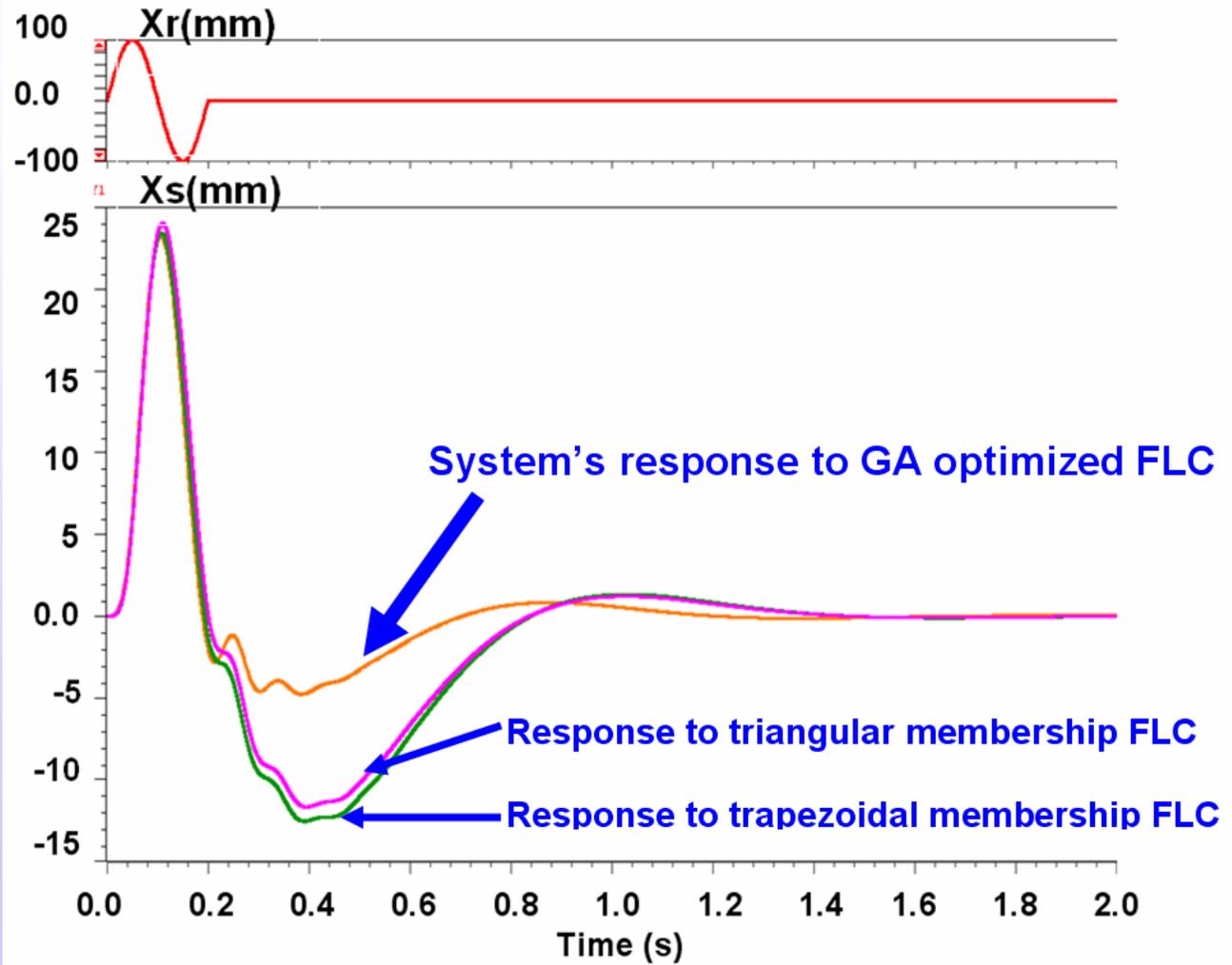
# Experimental results

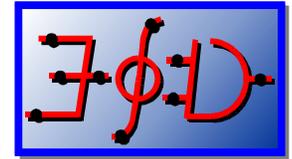
- GA optimized membership functions with irregular shapes
  - Acceleration





# Simulation waveforms

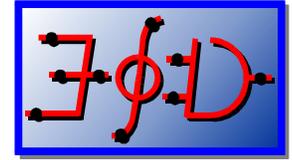




## Peak-to-peak and RMS values of $x_s(t)$

FLC types	Peak-to-peak (mm)	RMS (mm)
GA optimized	28.0	4.6
Triangular	35.7	6.2
Trapezoidal	36.0	6.4





## Conclusion

- **A novel way to improve FLC performance developed and successfully implemented in an HDL**
- **Novel approach to hardware performance optimisation proposed and implemented**
  - **Integrated VHDL-AMS optimiser using parallel GA**
- **New type of FLC with irregular membership functions proposed for automotive active suspension system**
  - **Superior performance to conventional FLCs with triangular or trapezoidal membership functions**
  - **More than 20% improvement in the peak-to-peak value of sprung mass displacement**



*Thank you!*

