BMAS 2005

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

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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

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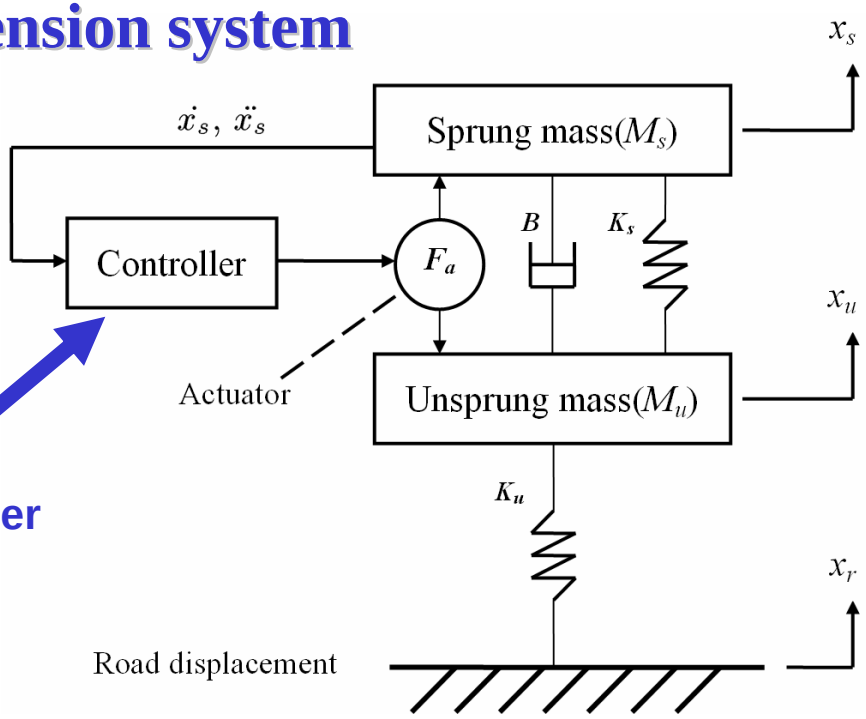
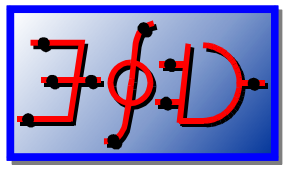
Introduction and system model

- 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

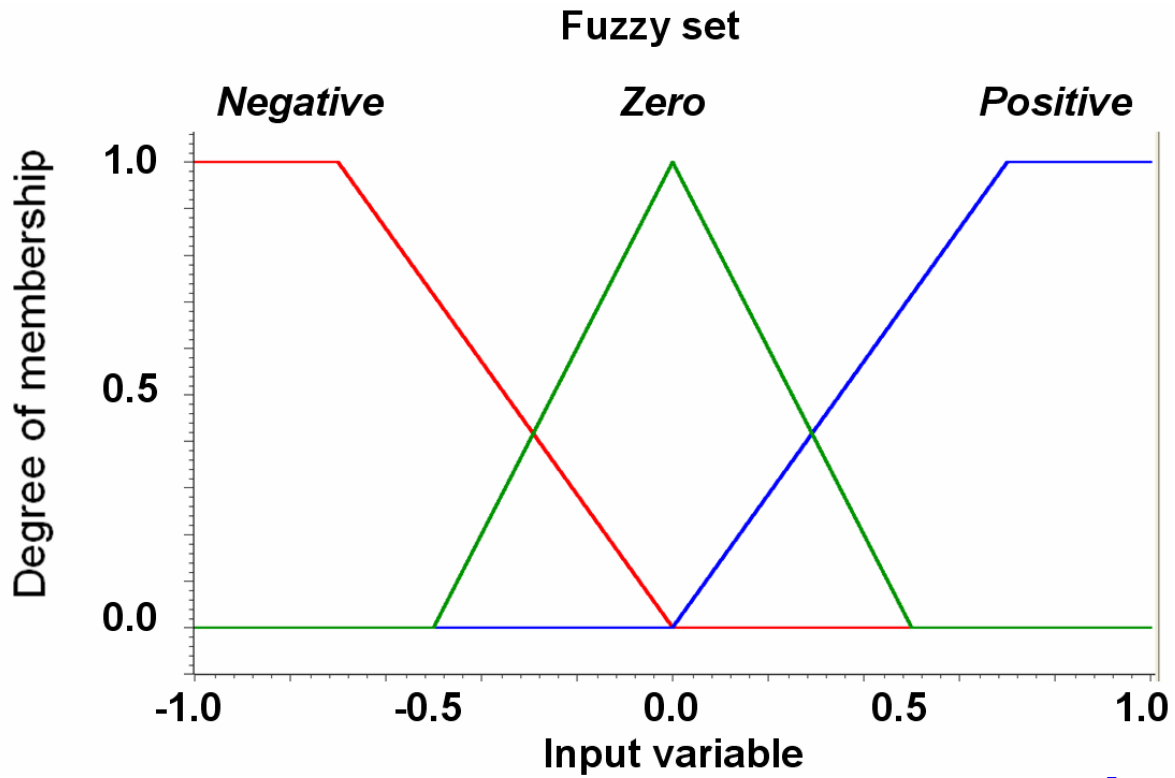


Fuzzy logic controller (FLC)

- 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**



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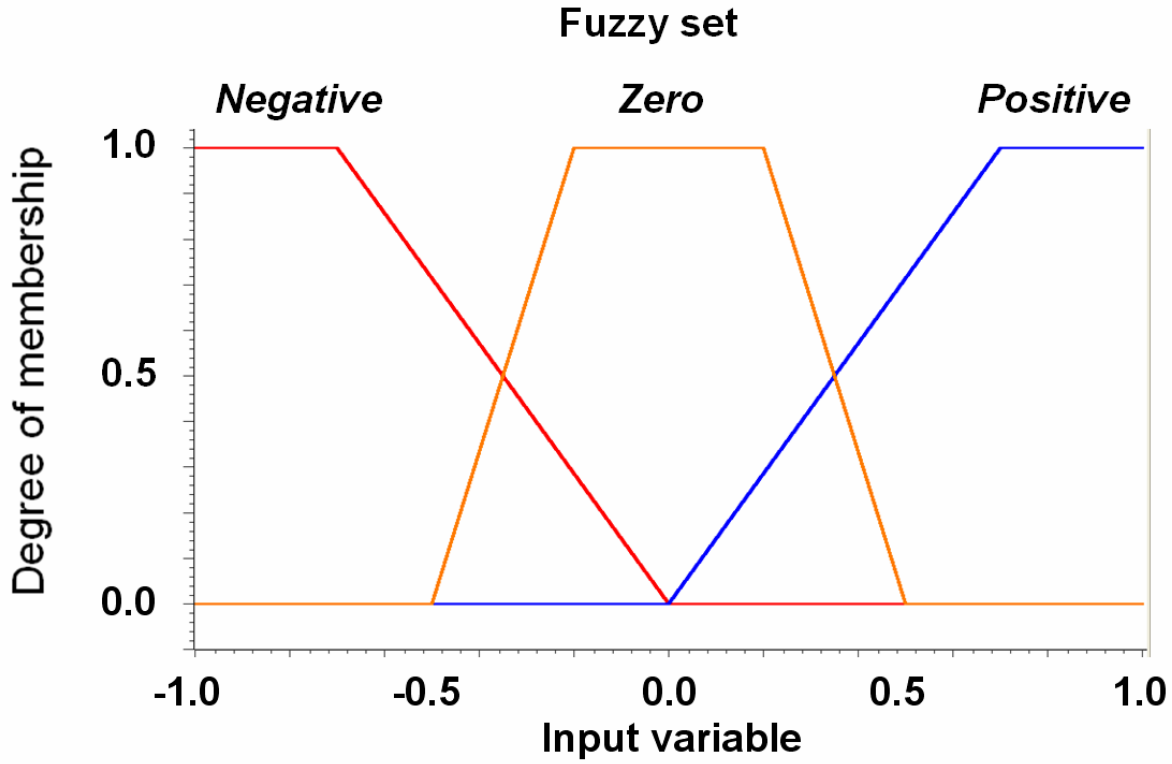
Fuzzy logic controller (FLC)

- Regular membership functions
  - Trapezoidal



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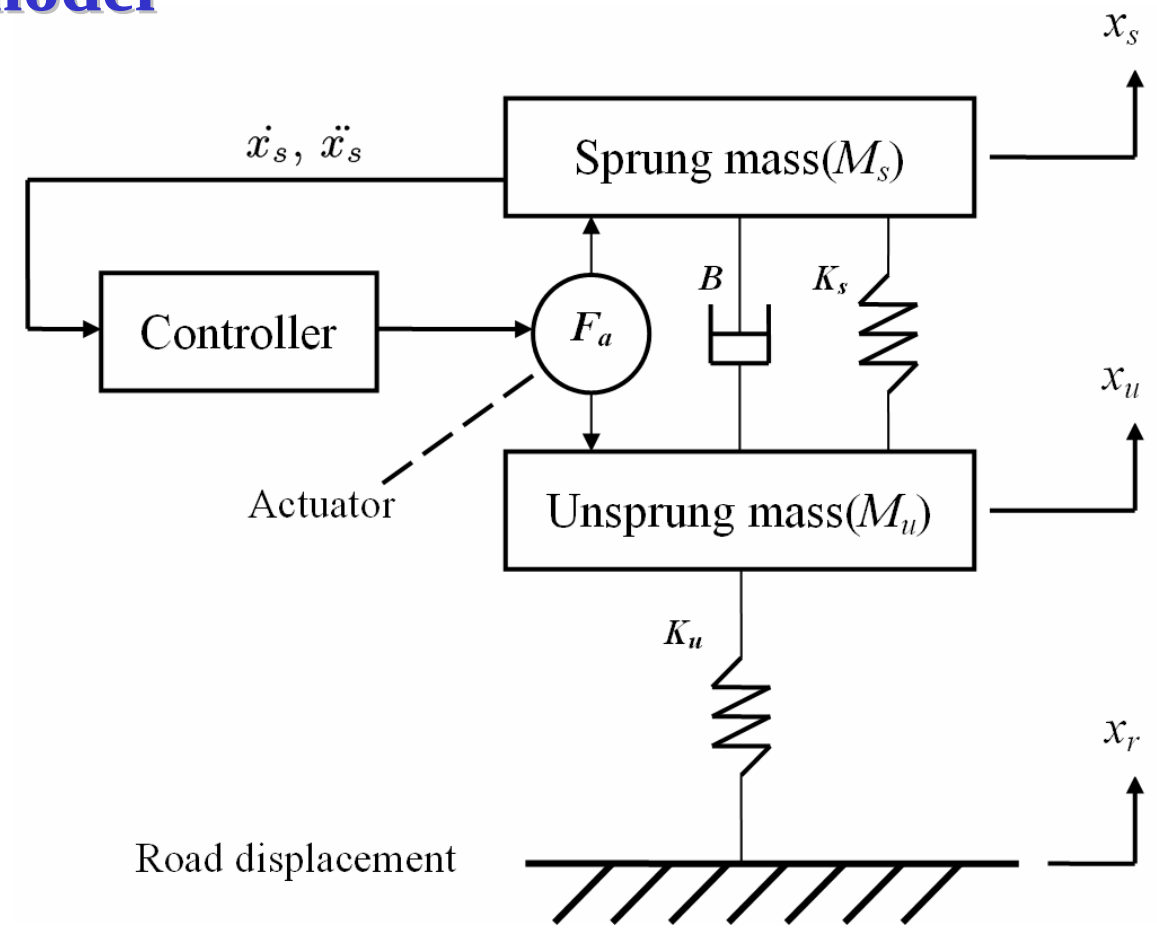
Genetic algorithm (GA)

- 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



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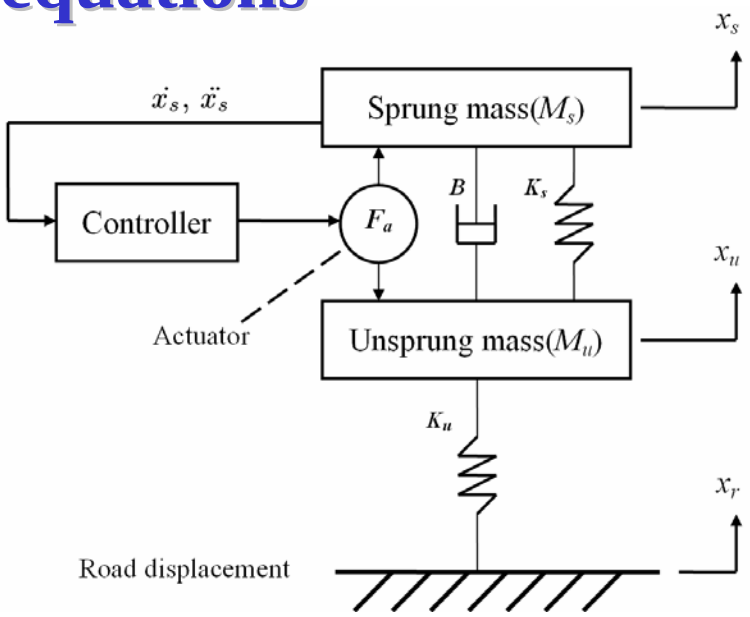
Sprung and unsprung mass equations



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

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

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

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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

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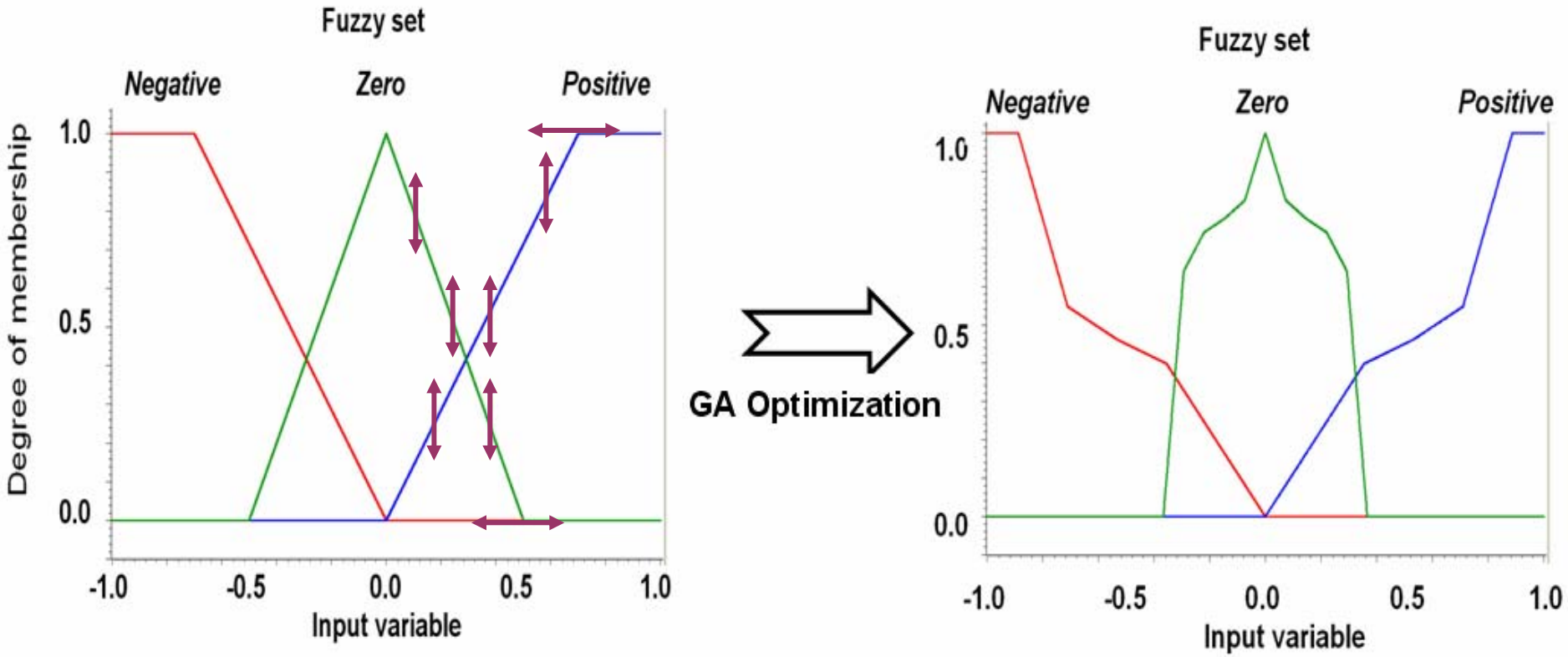
Shape optimization of fuzzy logic membership functions



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Integrated GA optimizer in VHDL-AMS testbench

- **Integrated hardware system performance optimizer wholly implemented in VHDL-AMS**
  - **Active suspension system**
  - **FLC**
  - **GA optimization**

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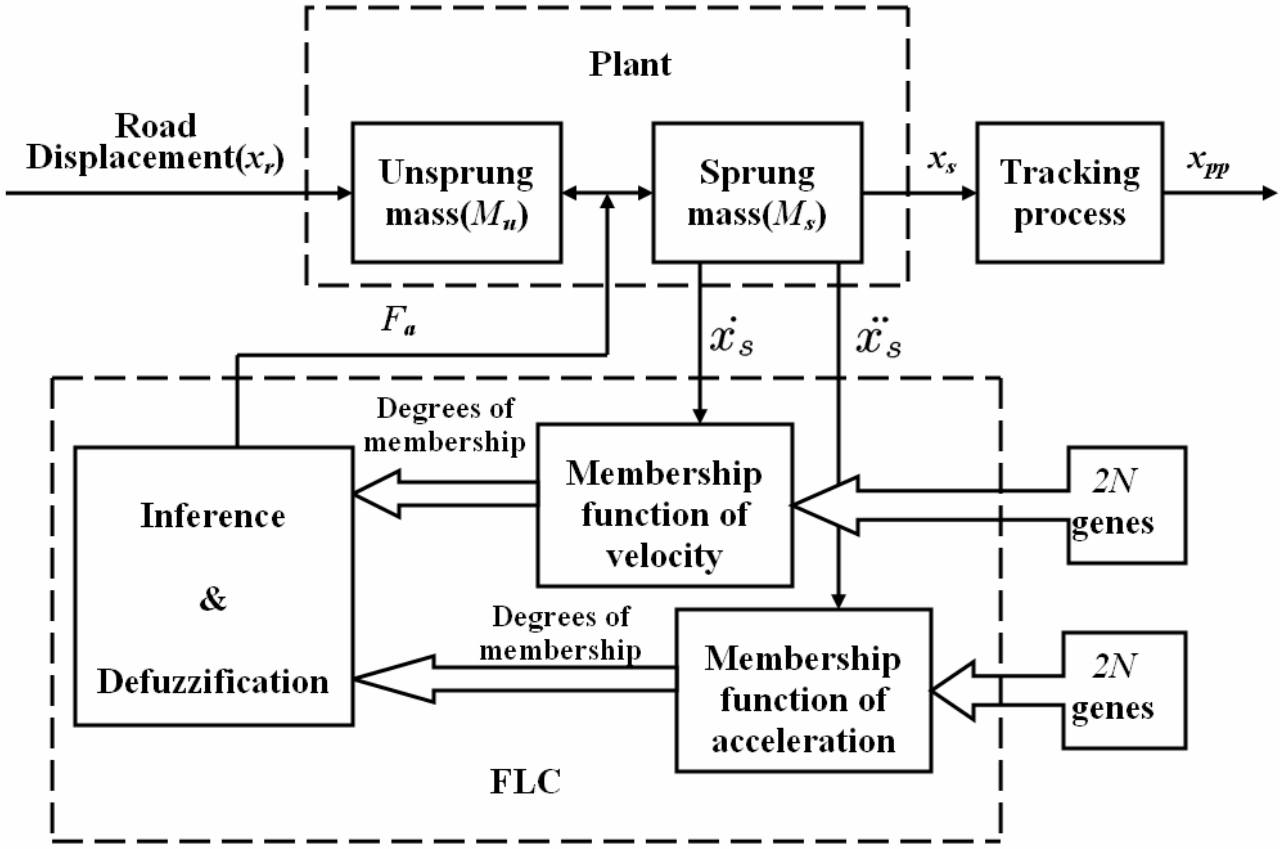
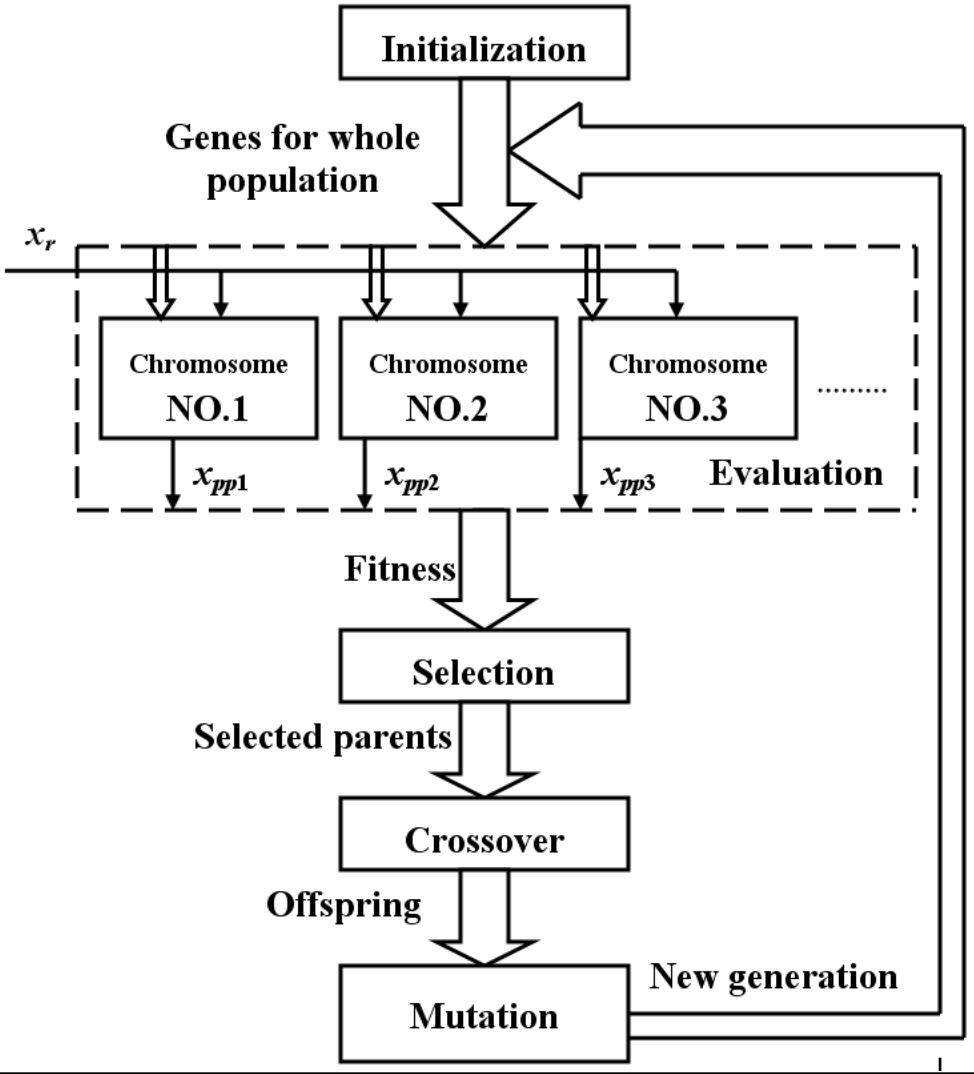
Block diagram of one chromosome (VHDL-AMS entity)



Flow chart of a parallel GA



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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

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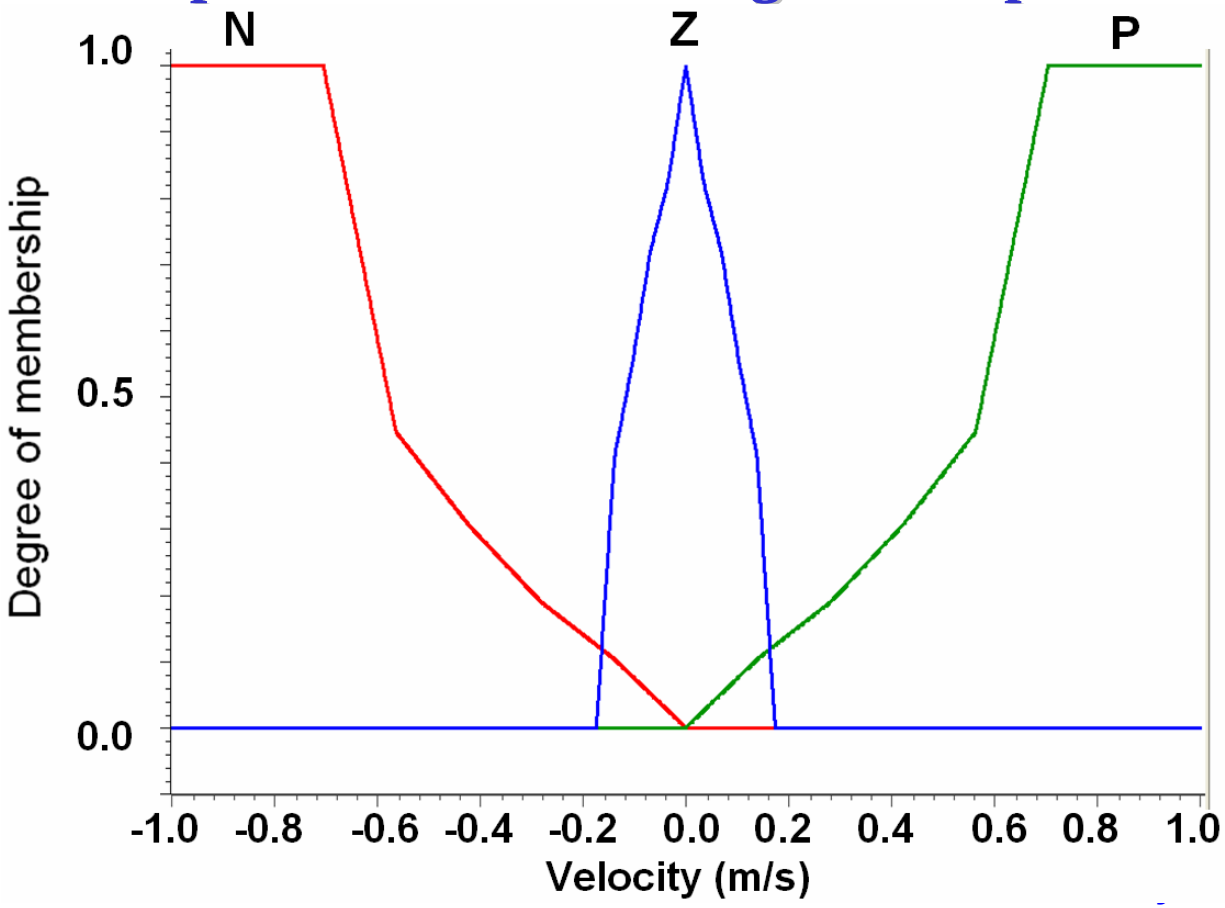
Experimental results

- GA optimized membership functions with irregular shapes
  - Velocity



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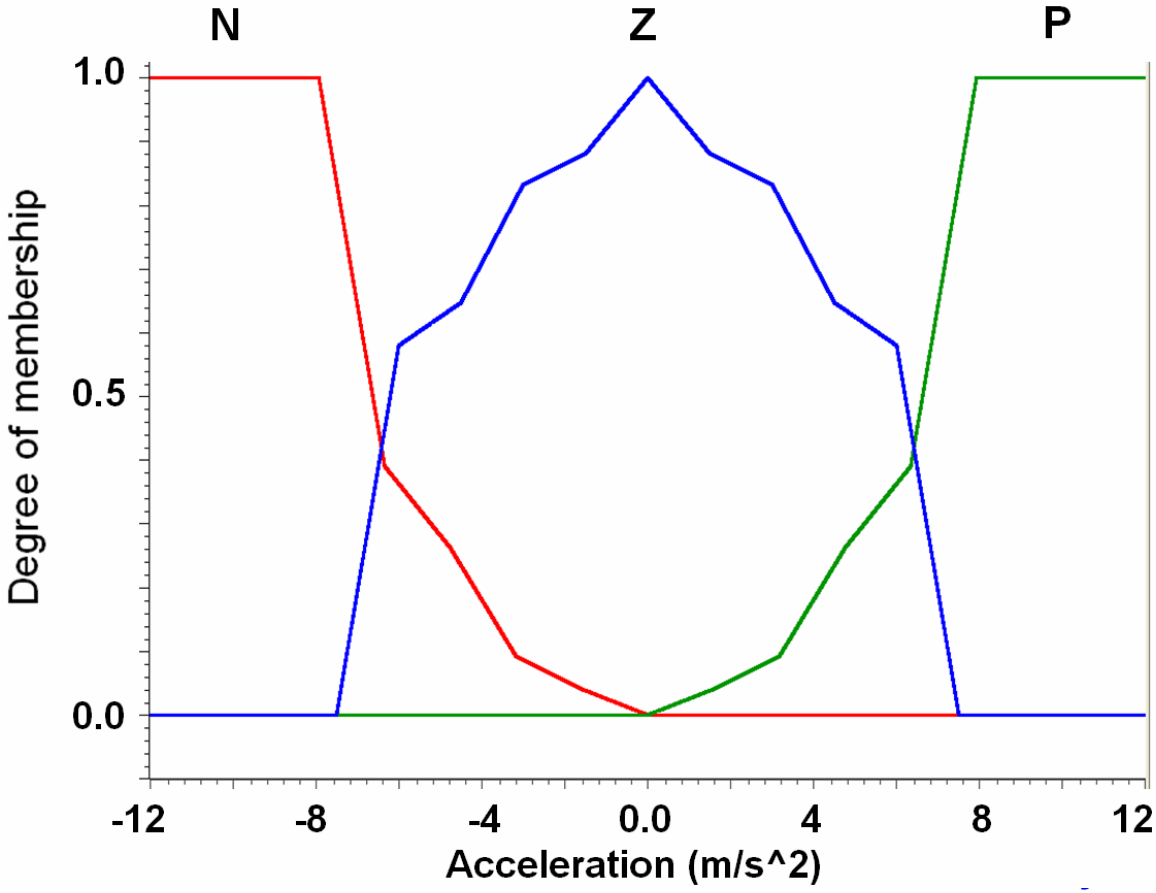
Experimental results

- GA optimized membership functions with irregular shapes
  - Acceleration



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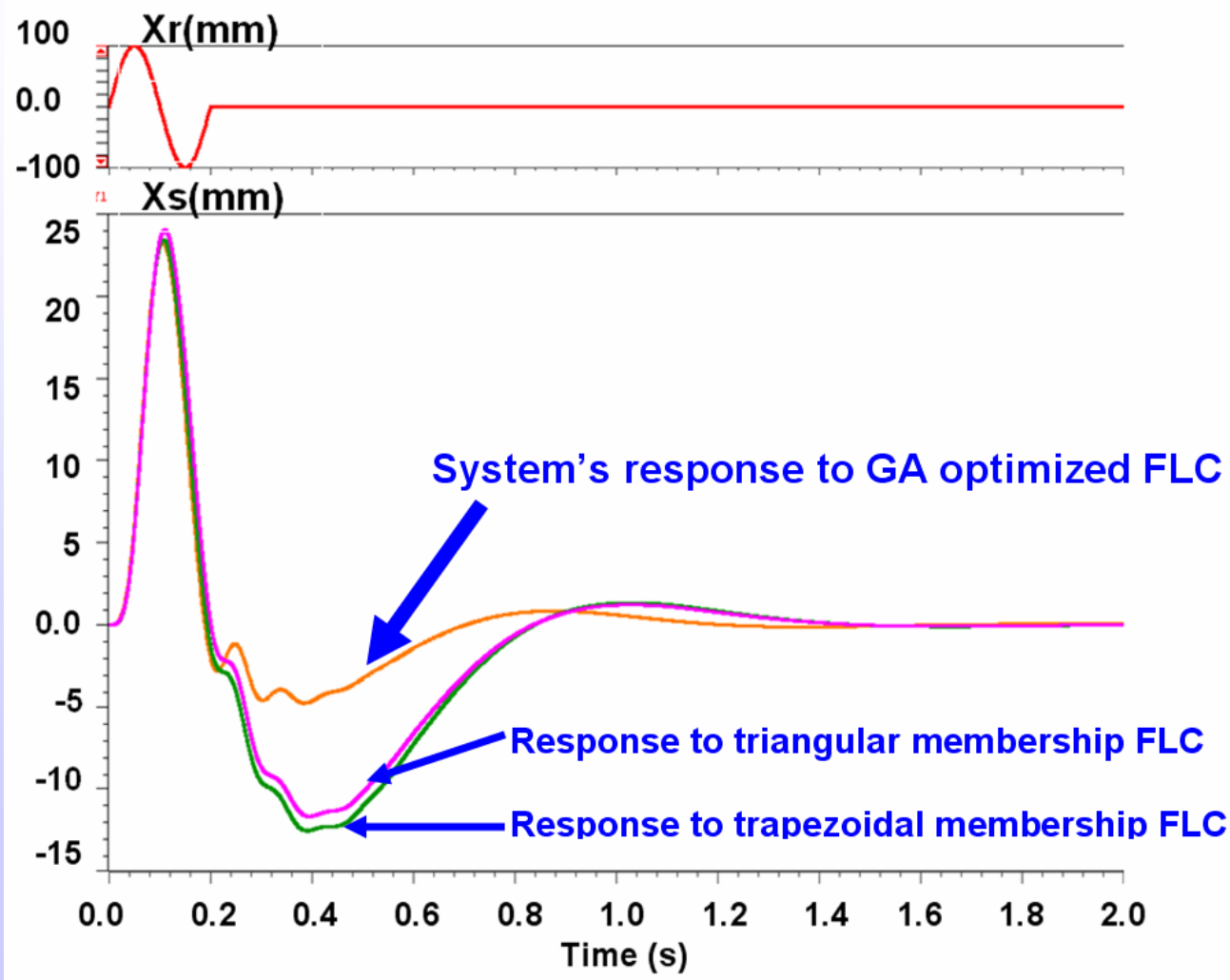
Simulation waveforms



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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!