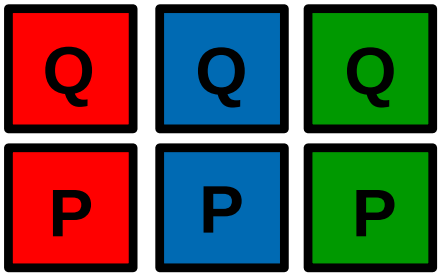
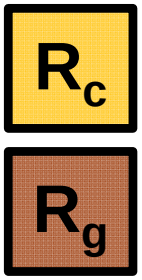
An Overview of Energy Saving Architectures for Mobile Applications

A framework to classify mobile hydraulic systems

S_A/S_D C_A/C_D





RWTH AACHEN UNIVERSITY

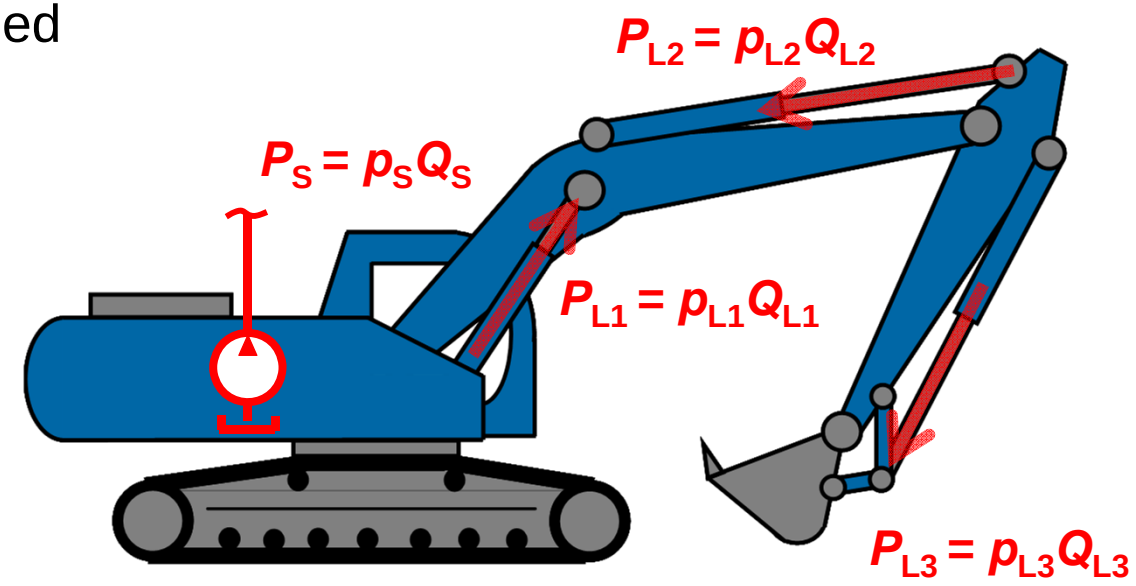
ifk

IFAS Institut für fluidtechnische Antriebe und Steuerungen

Hubertus Murrenhoff
March 25, 2014

Introduction and Motivation

- Mobile machines have multiple actuators
- Operator's task is to regulate the speed of each actuator and drive
- Standard hydraulic architectures suffer from low efficiency
- To increase efficiency
  - Decrease throttling losses
  - Avoid inefficient operating points
  - Recover potential energy

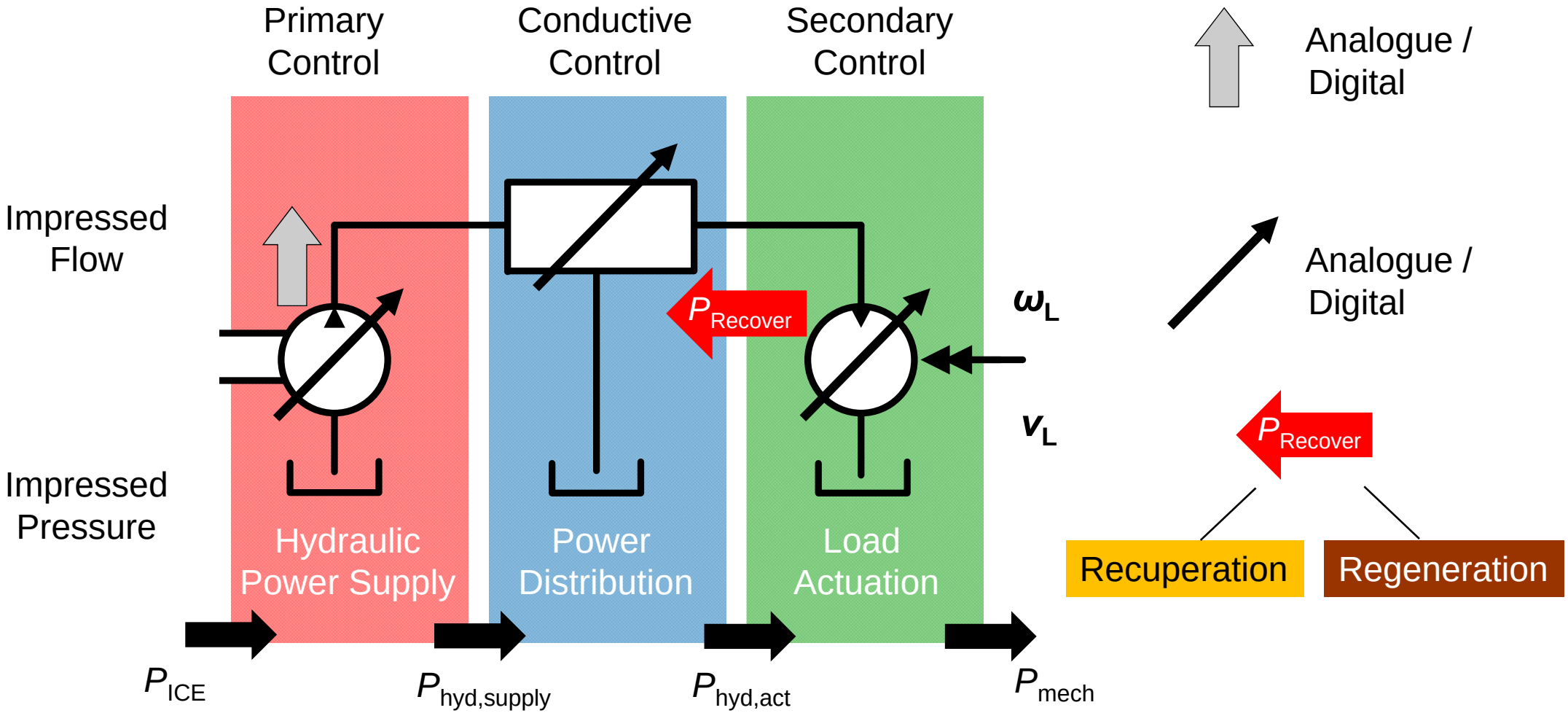


Aim of this presentation: Establish a framework to classify current system architectures and to aid in the development of new architectures

Outline

- Introduction and Motivation
- Framework
- Energy Saving Architectures
- Conclusion and Outlook

Hydraulic System Architectures



Goal: Regulate ω_L (rotary actuator) or v_L (linear actuator)

Framework

- A barcode is used to classify each system

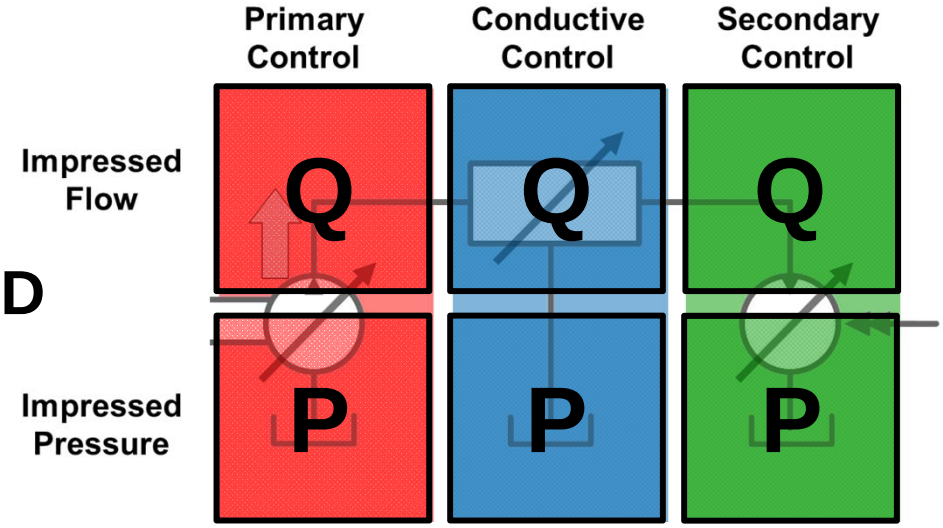
Supply

S_A / S_D

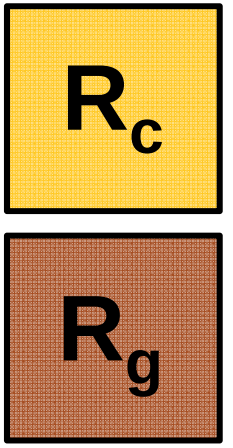
Control

C_A / C_D

Supply / Control Concept



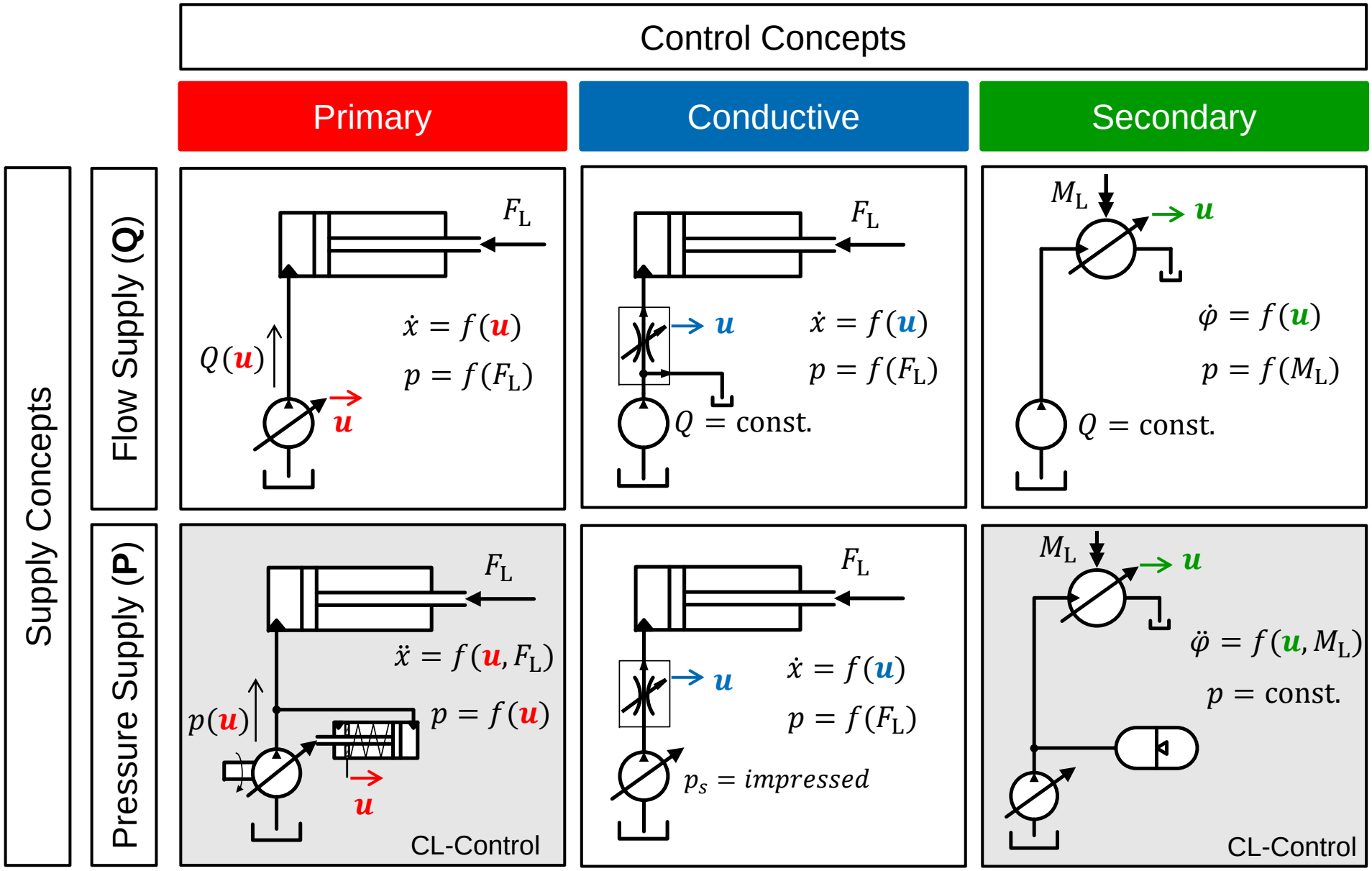
Energy Recovery



Recup.

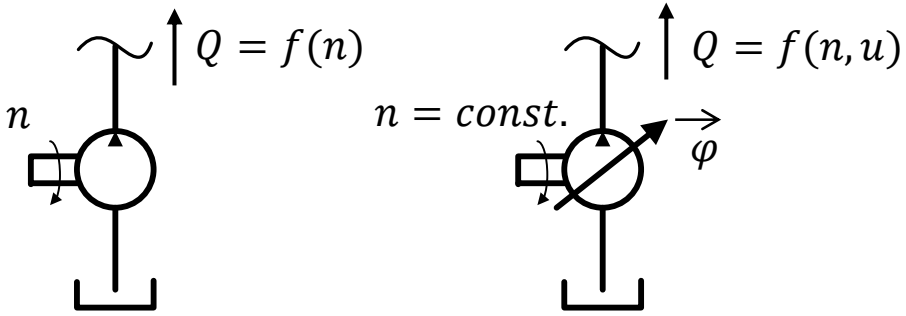
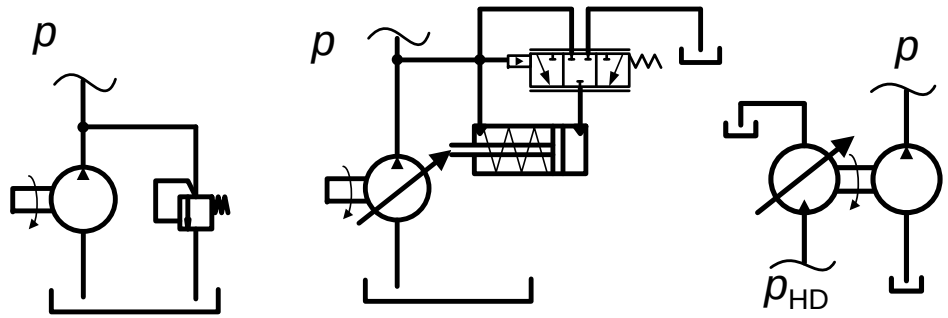
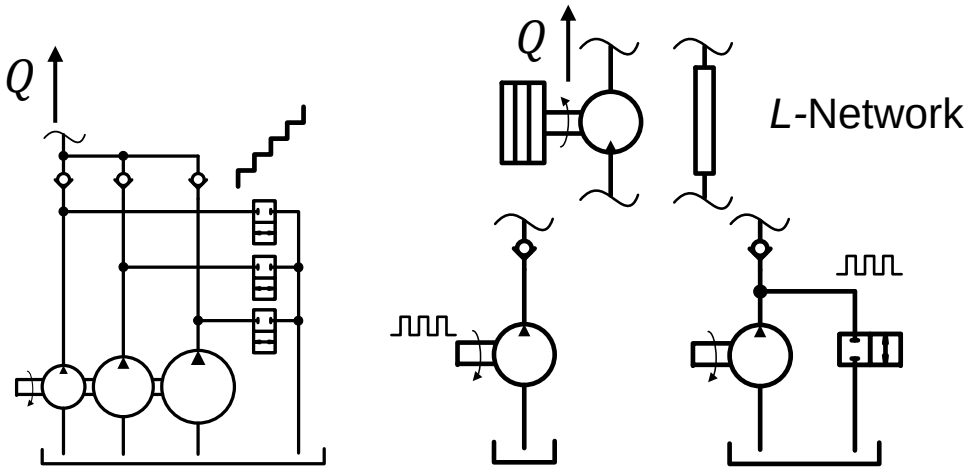
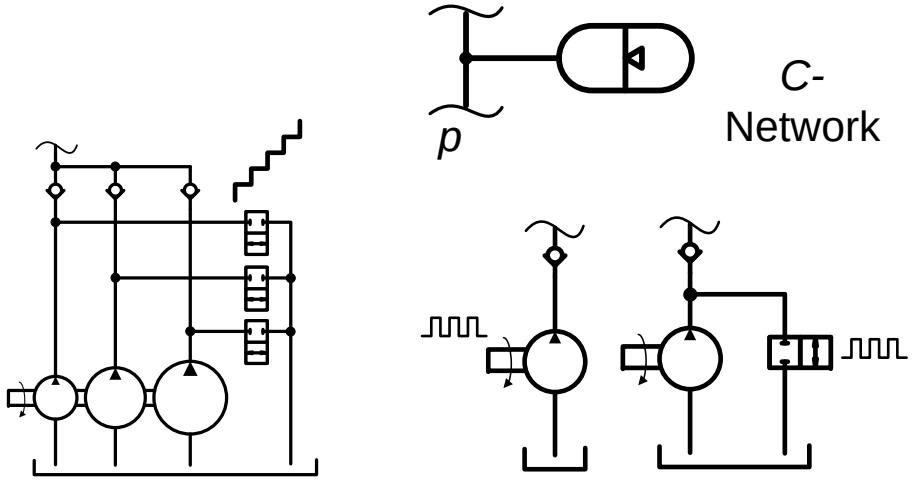
Regen.

Supply / Control Concepts



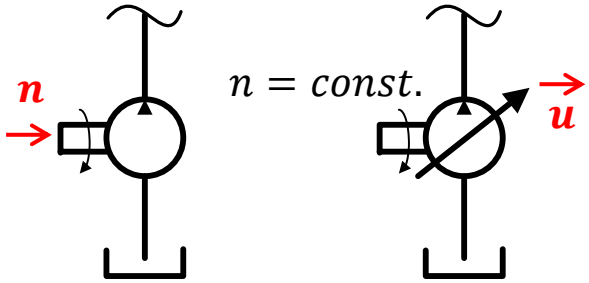
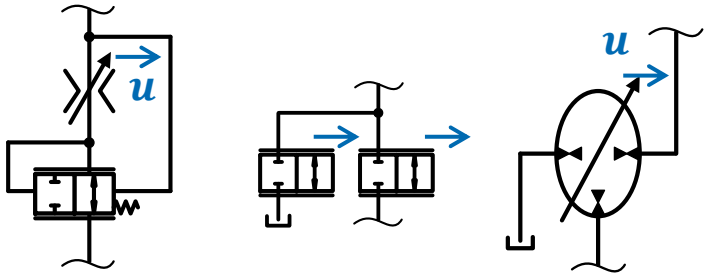
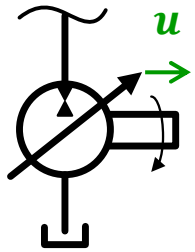
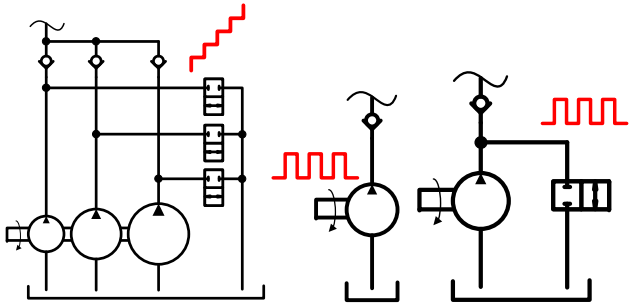
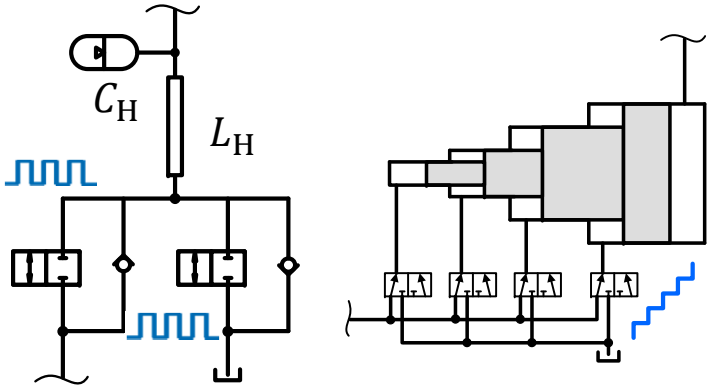
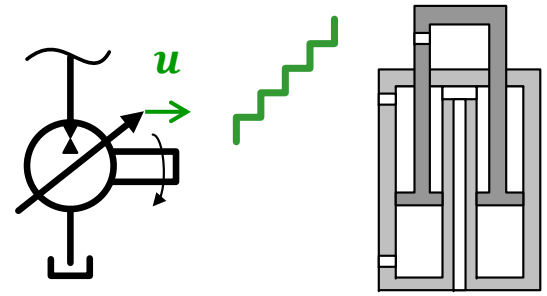
*Examples of **Supply** Concepts*

S_A/S_D

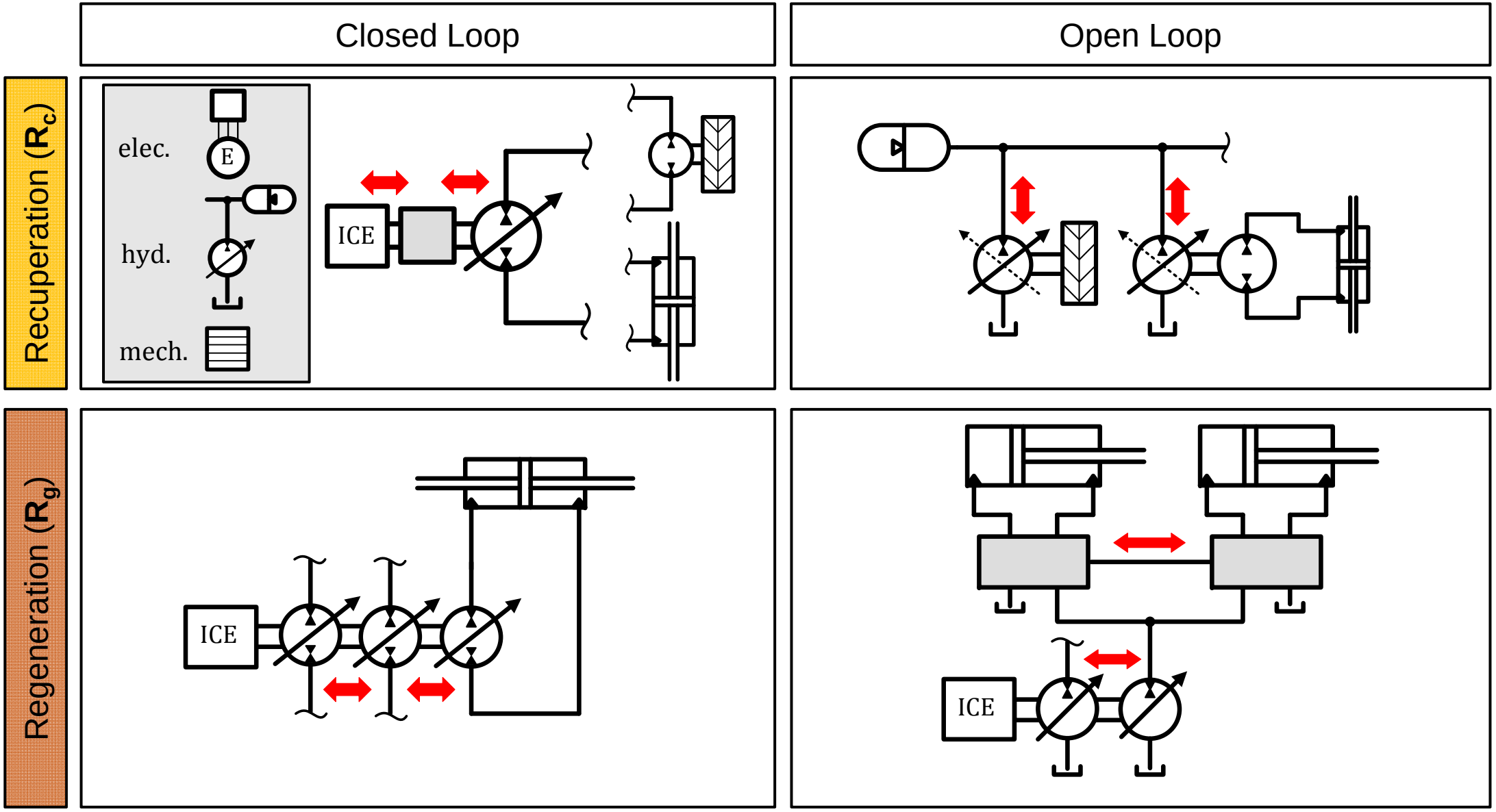
	Flow Supply Concepts (**Q**)	Pressure Supply Concepts (**P**)
Analogue **(A)**	 Fixed Displacement Variable Displacement	 Fixed Displacement Variable Displacement
Digital **(D)**	 Multiple Pumps Single Pumps with *L*-Network	 Multiple Pumps Single Pumps

*Examples of **Actuator Control** Concepts*

C_A/C_D

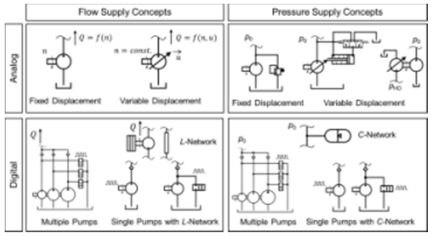
	Control Concepts		
	Primary	Conductive	Secondary
Analogue (**A**)	$p, Q = f(\boldsymbol{n})$ $p, Q = f(\boldsymbol{u})$ 		 $M = f(\boldsymbol{u})$ $Q = f(Load)$
Digital (**D**)			

Energy Recovery Concepts

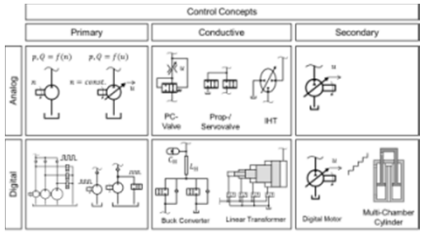


Classification Barcode

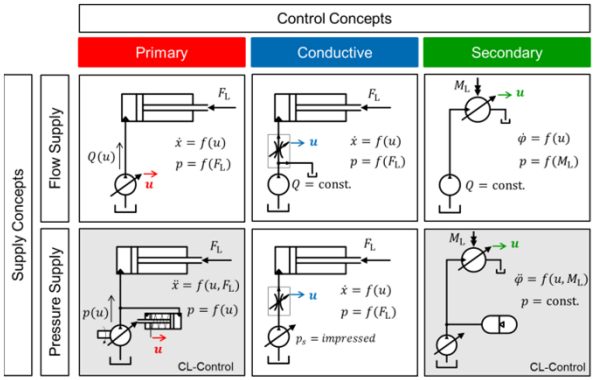
Supply



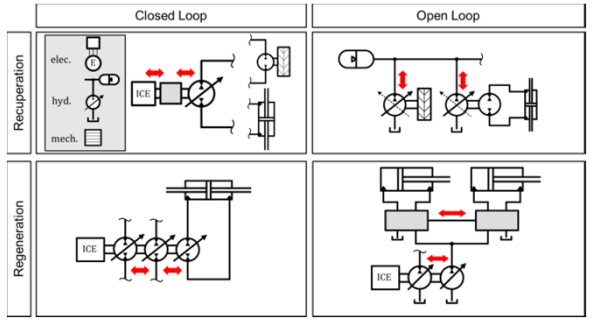
Control



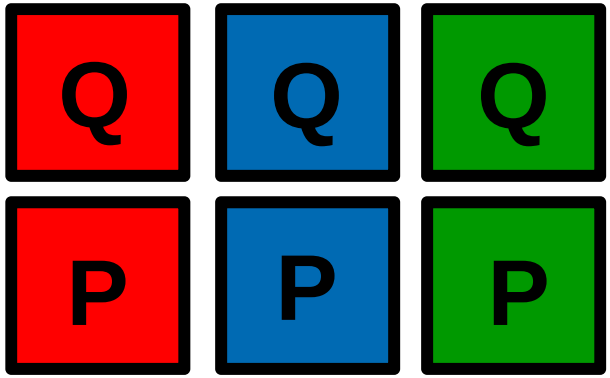
Supply / Control Concept

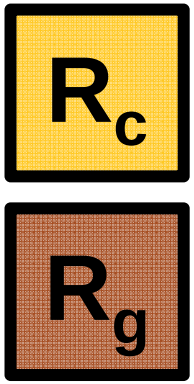


Energy Recovery



S_A/S_D **C_A/C_D**





Outline

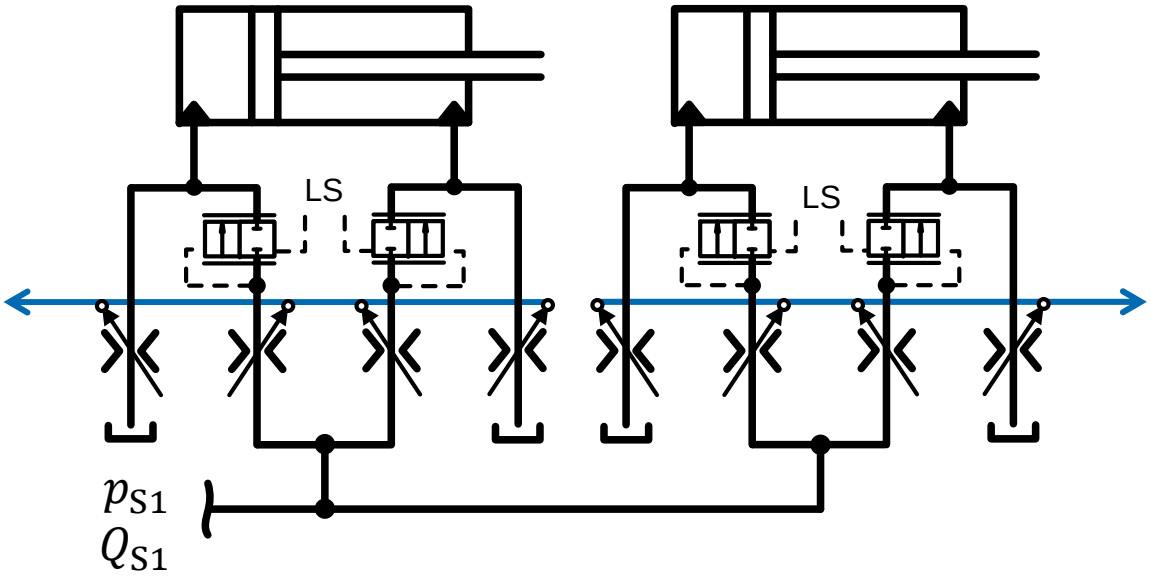
- Introduction and Motivation
- Framework
- Energy Saving Architectures
- Conclusion and Outlook

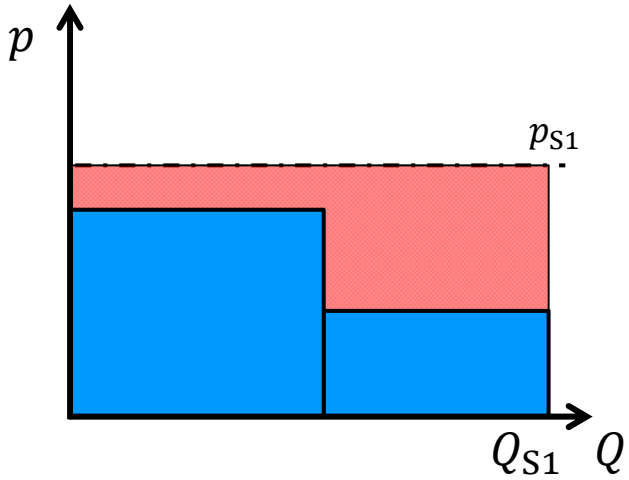
Industry Standard – Load Sensing

S_A C_A Q Q Q / P P P / R_c / R_g

- Pump flow matched to flow demand of all actuators
- Pump pressure is matched to highest load pressure
- Large throttling losses (Inlet and outlet flow)
- One pump for multiple actuators
- No possibility of energy regeneration

Throttling losses	☹
Operating point	😐
Energy recovery	☹
Investment costs	☺



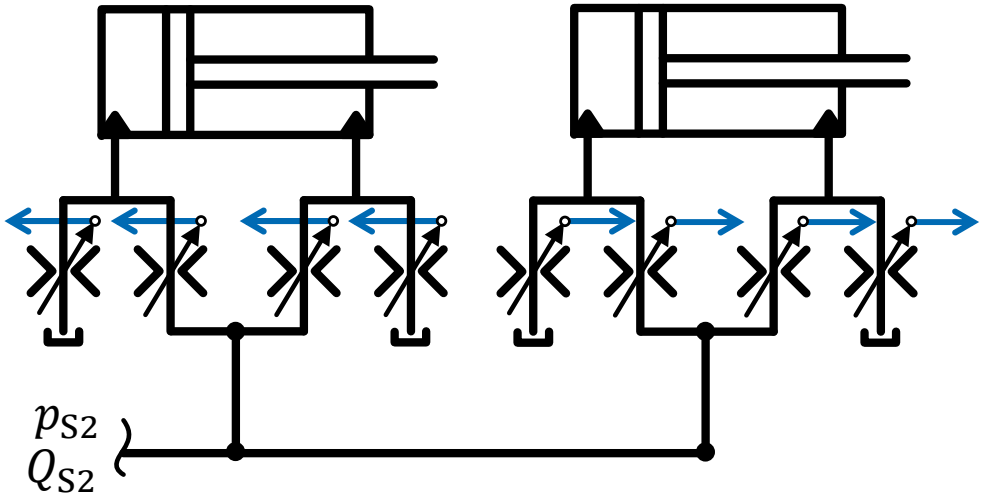


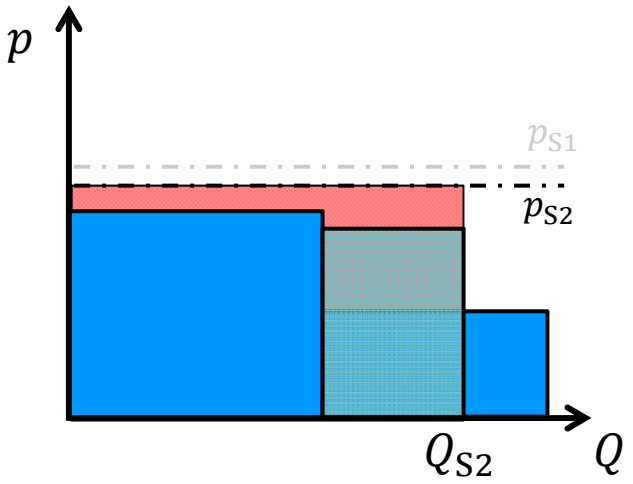
- Companies: Linde LSCS Rexroth LUDV

Research – Independent Metering (IM)

- Reduced throttling losses (Inlet and tank side)
- Required pump flow can be reduced
- Possibility of energy regeneration
- High quality valves and control needed

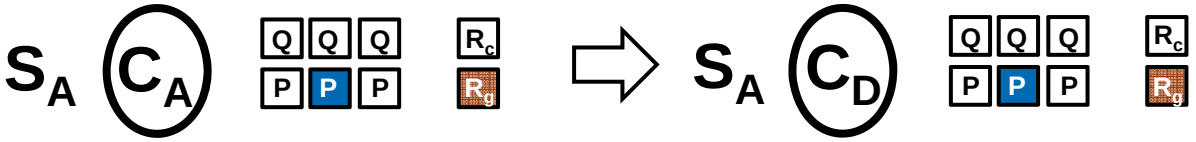
Throttling losses	😐
Operating point	😐
Energy recovery	🙂
Investment costs	🙂





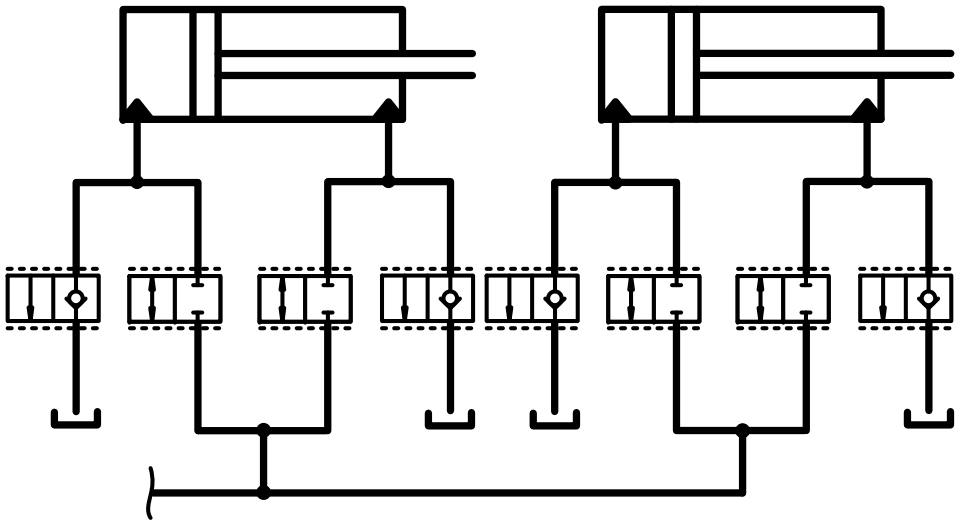
- Research conducted by: Backé (IFAS) 1973, Liu (Purdue) 2002, Jansson (Linköping) 1990, Shenouda (Georgia Tech) 2006

- Independent metering requires high response valve



Throttling losses	😐
Operating point	😐
Energy recovery	🙂
Investment costs	🙂

- Digital valves are simple on/off valves, allow affordable high response control



- Pressure peaks and smooth motion control are challenges

- Research conducted by: Bower 1961

  Linjama (Tampere) 2005

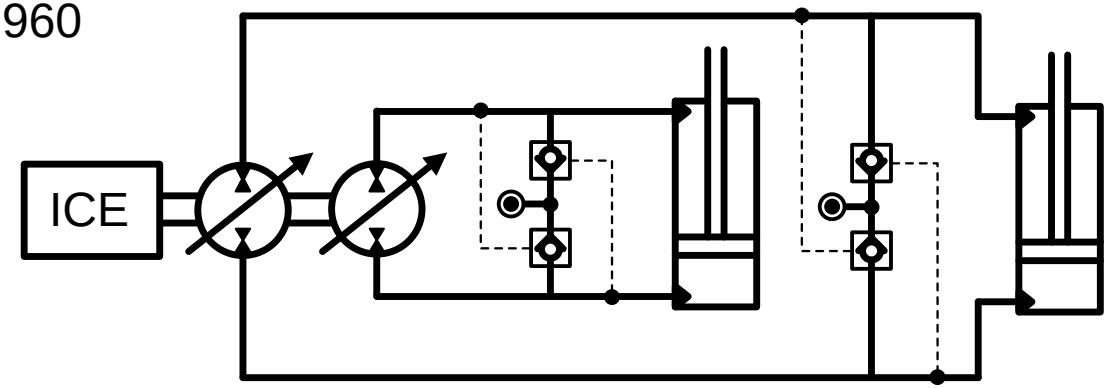
Research – Displacement Control (DC)

S_A C_A Q Q Q P P P R_c R_g

- Each actuator has its own dedicated displacement unit
- No inherent throttling losses
- Displacement units are dimensioned for peak flow
- Possibility of energy regeneration

Throttling losses	☺
Operating point	☹
Energy recovery	☺
Investment costs	☹

- DC for motors and double rod cylinders
  - Blackburn, Reethof, Shearer (MIT) 1960



- DC for single rod cylinder:
  - Berbuer (IFAS) 1988

- Current research
  - Williamson, Hippalgaonkar, Ivantysynova (Purdue)

Research – Open loop displacement control S_A C_A/C_A Q Q Q / P P P R_c R_g

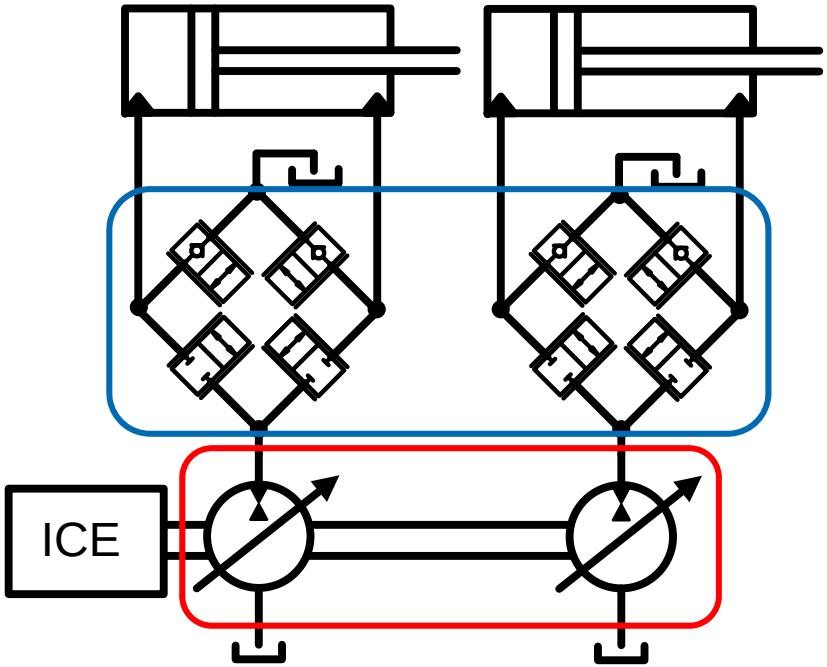
- DC-Control has great potential but suffers from part loading losses.
- Independent Metering (IM) allows for the reduction in pump flow.

Throttling losses	☺
Operating point	😐
Energy recovery	☺
Investment costs	☹

S_A C_A Q Q Q / P P P R_c R_g + IM = S_A C_A/C_A Q Q Q / P P P R_c R_g

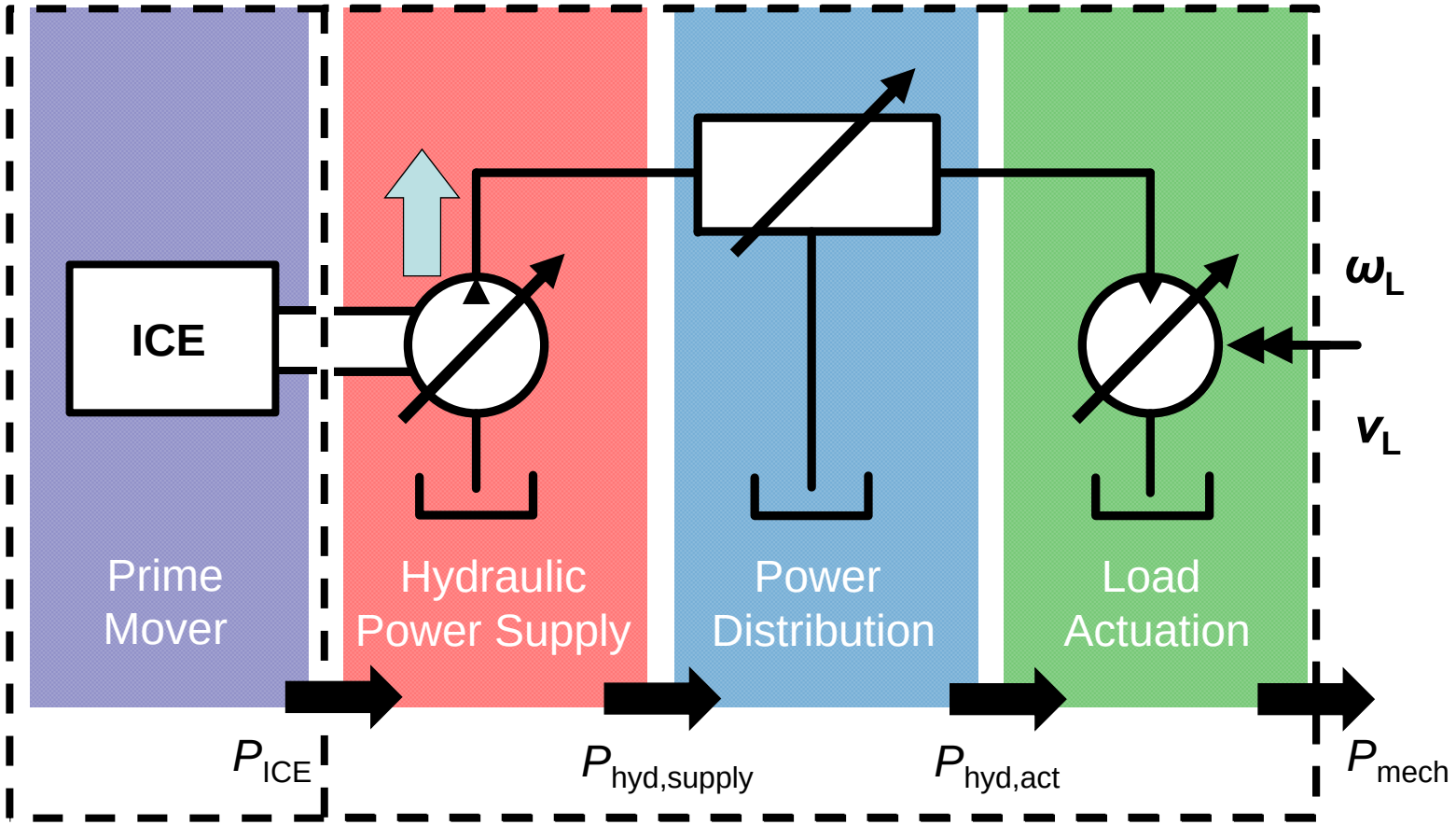
- Valves are used for flow regeneration
- Smaller displacement units compared to DC
- Less part loading

- Research conducted by
  - Heybroek (Linköping) 2008



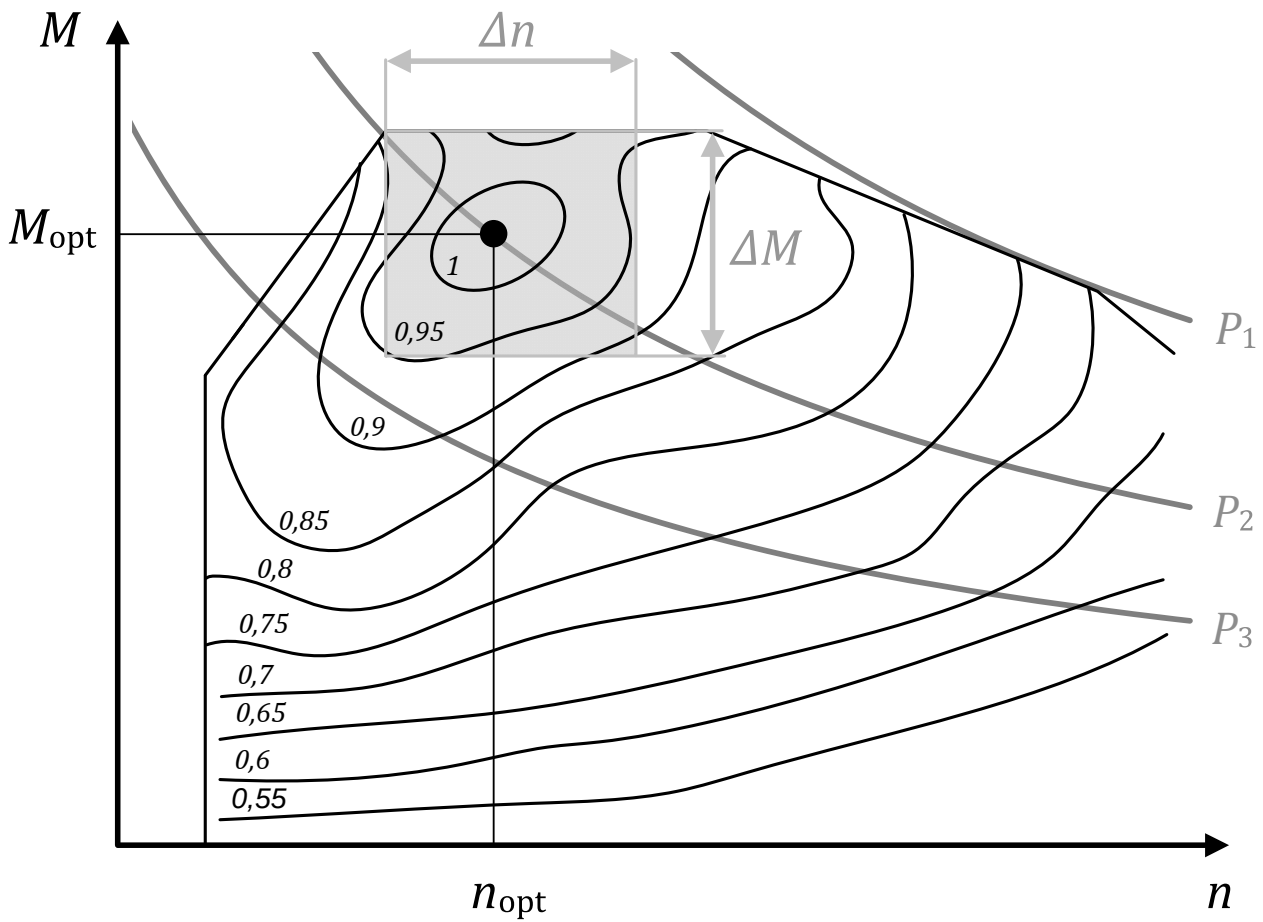
Holistic Drive Design

- To design more efficient drives it is neccesary to consider the whole system including the prime mover.



Holistic Drive Design

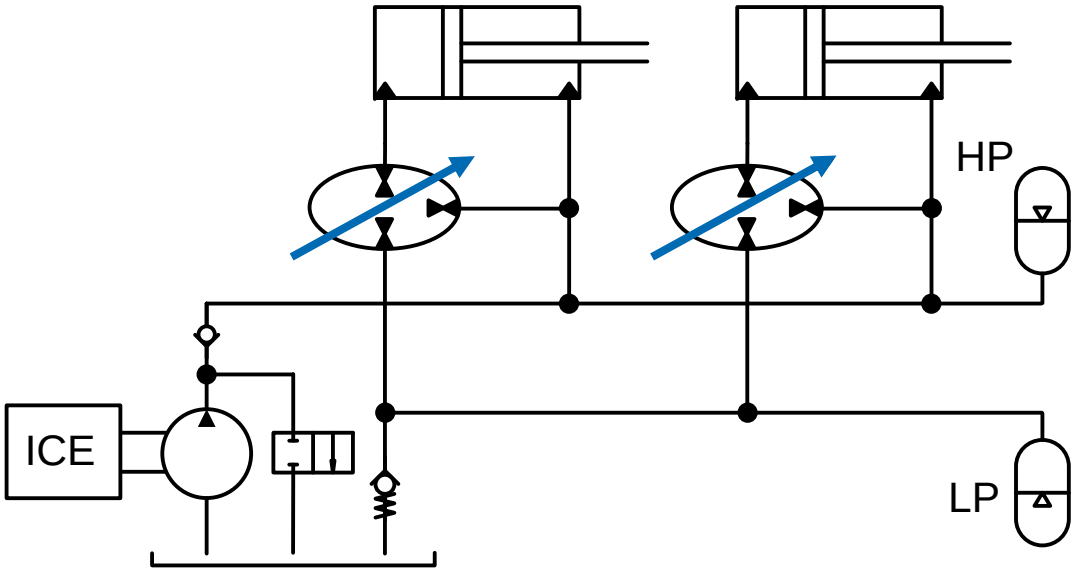
- To design more efficient drives it is neccesary to consider the whole system including the prime mover.



Research – Constant Pressure Systems

- Hydraulic Transformer
  - No throttling losses caused by the control principle
  - Energy efficient operation of the combustion engine

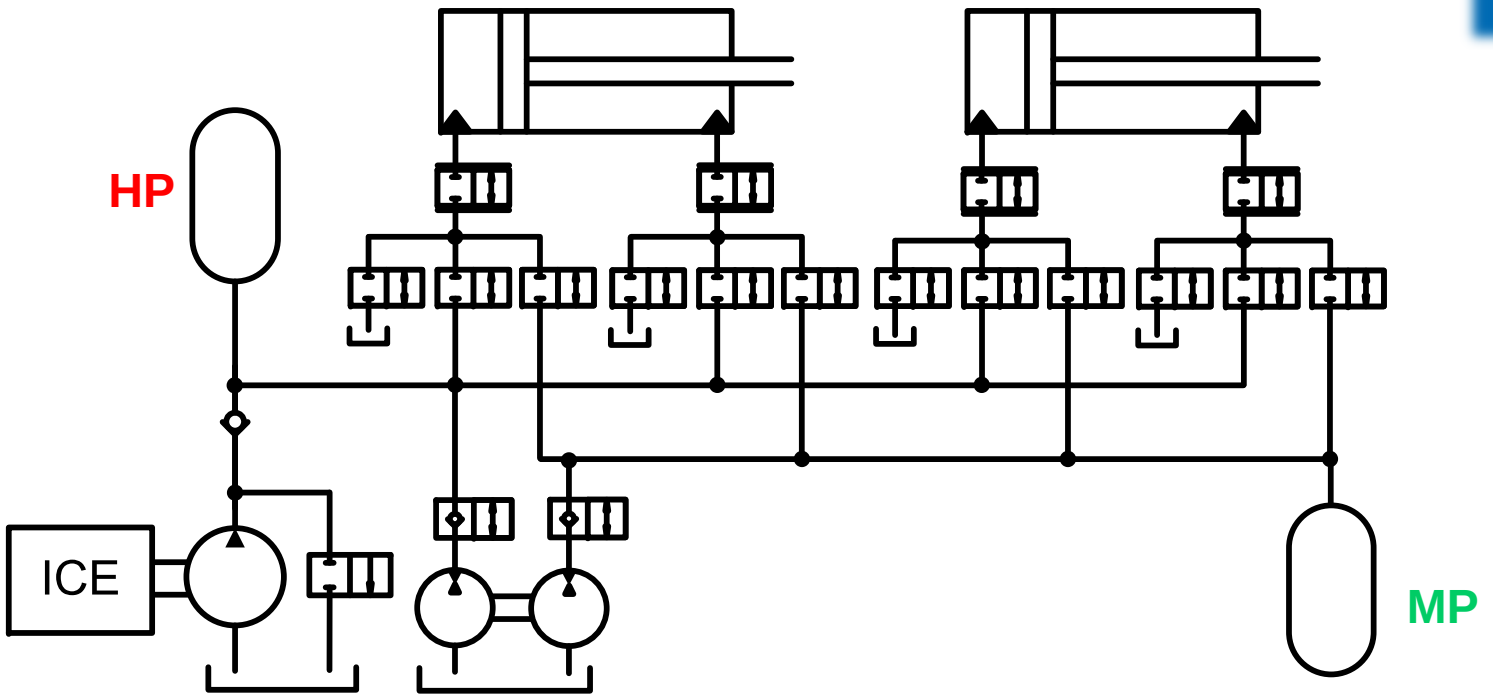
Throttling losses	☺
Operating point	☺
Energy recovery	☺
Investment costs	☹



- Commercially available units are awaited
- Research conducted by: Achten (Innas)

- STEAM: Constant pressure system → const. ICE load
- Intermediate pressure rail to minimise throttling losses
- Use of analogue and digital valves

Throttling losses	😐
Operating point	🙂
Energy recovery	🙂
Investment costs	🙂



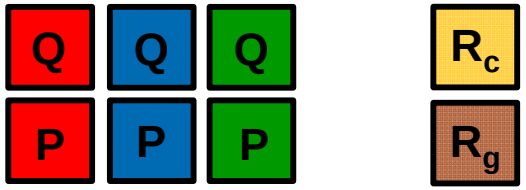
Outline

- Introduction and Motivation
- Framework
- Energy Saving Architectures
- Conclusion and Outlook

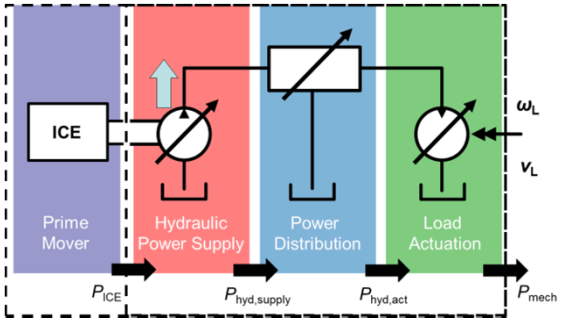
Summary & Outlook

- Introduced a framework to classify mobile hydraulic systems
- Framework allows for the development of new architectures

S_A/S_D C_A/C_D



- An efficient mobile hydraulic system aims to:
  - Minimise throttling losses
  - Avoid inefficient operating points
  - Use energy recovery
- Holistic drive design is the way forward



- Investigate hybrid systems, (analogue + digital) or (primary + conductive control)
- Use of mathematical tools to design new system topologies and its controls
- Development of new components to meet system requirements

Thank you for your attention.

Questions, Suggestions?

RWTH AACHEN UNIVERSITY

IFK

IFAS Institut für fluidtechnische Antriebe und Steuerungen