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# From Cooking to Advanced Manufacturing --Controls, Automation, and Beyond

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Xu Chen

Department of Mechanical Engineering  
University of Washington



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# Ingredients of Kung Pao Chicken

## Marinade

- 1 tablespoon soy sauce
- 2 teaspoons Chinese rice wine or dry sherry
- 1 1/2 teaspoons cornstarch
- 1 pound boneless, skinless, chicken breasts or thighs, cut into 1-inch cubes

## Sauce

- 1 tablespoon Chinese black vinegar, or substitute good-quality balsamic vinegar
- 1 teaspoon soy sauce
- 1 teaspoon hoisin sauce
- 1 teaspoon sesame oil
- 2 teaspoons sugar
- 1 teaspoon cornstarch
- 1/2 teaspoon ground Sichuan pepper
- 2 tablespoons peanut or vegetable oil
- 8 to 10 dried red chilies
- 3 scallions, white and green parts separated, thinly sliced
- 2 garlic cloves, minced
- 1 teaspoon minced or grated fresh ginger
- 1/4 cup unsalted dry-roasted peanuts



Courtesy of Diana Kuan

# The Cooking Procedure

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# The Difference of Controls

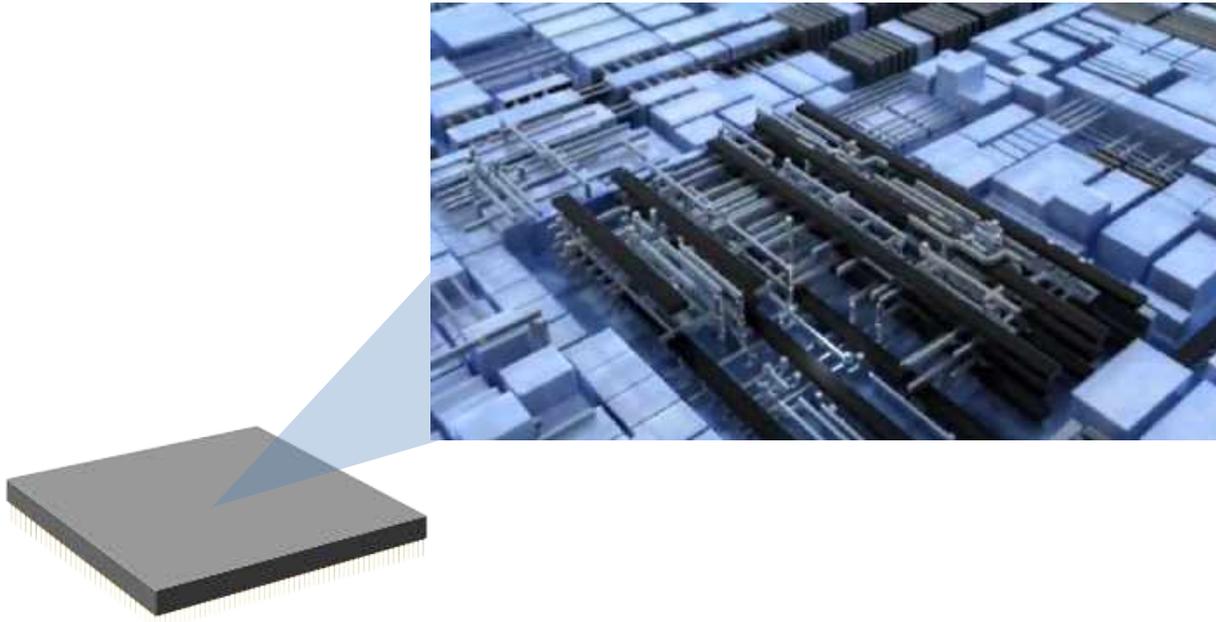
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Courtesy of Diana Kuan

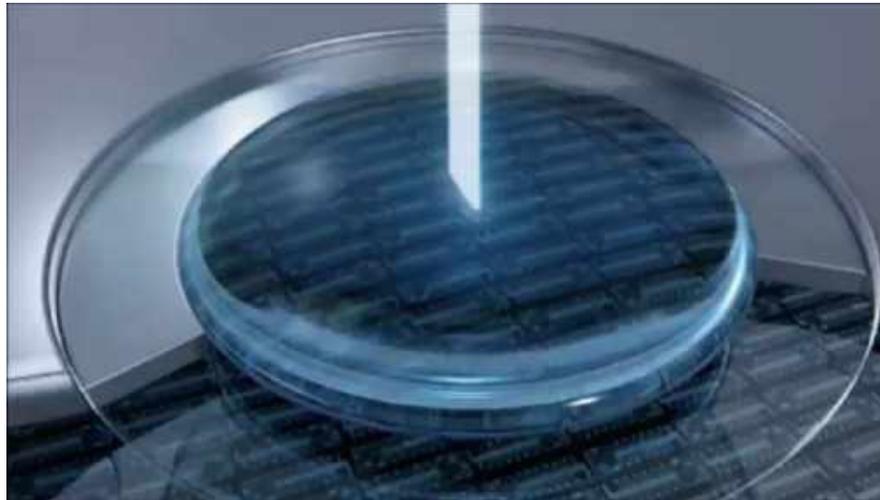
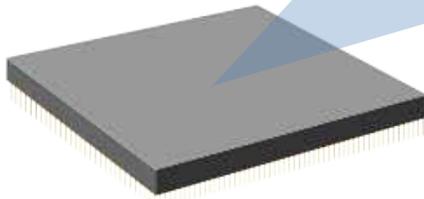
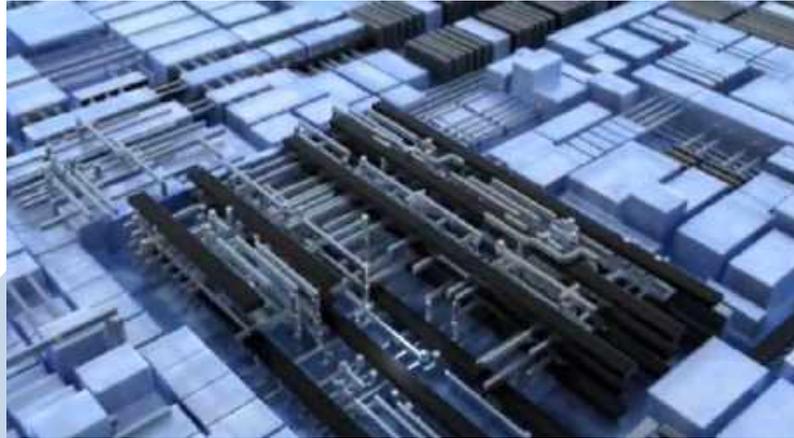
# Semiconductor Manufacturing

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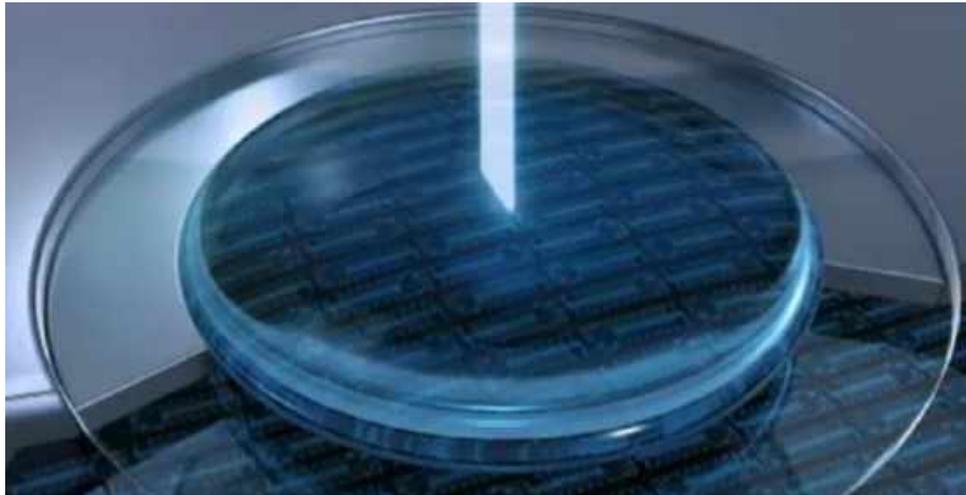


# Semiconductor Manufacturing

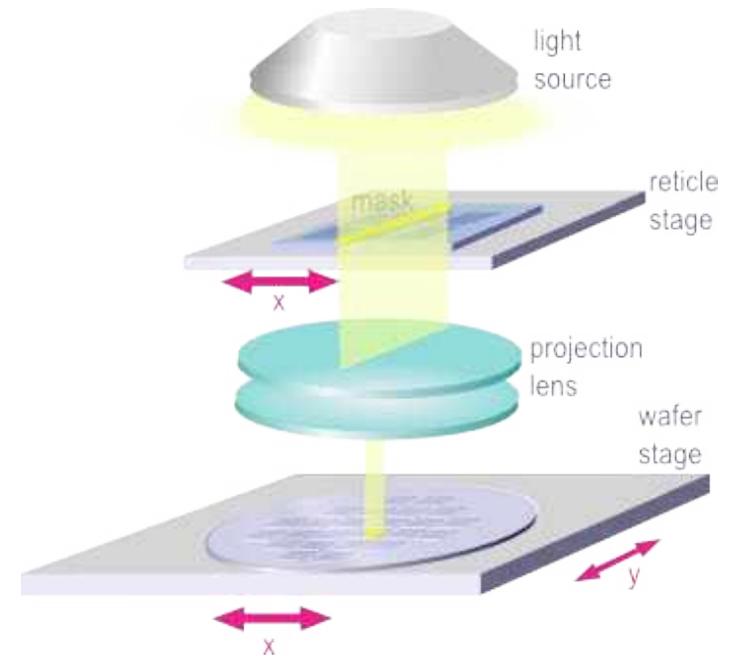
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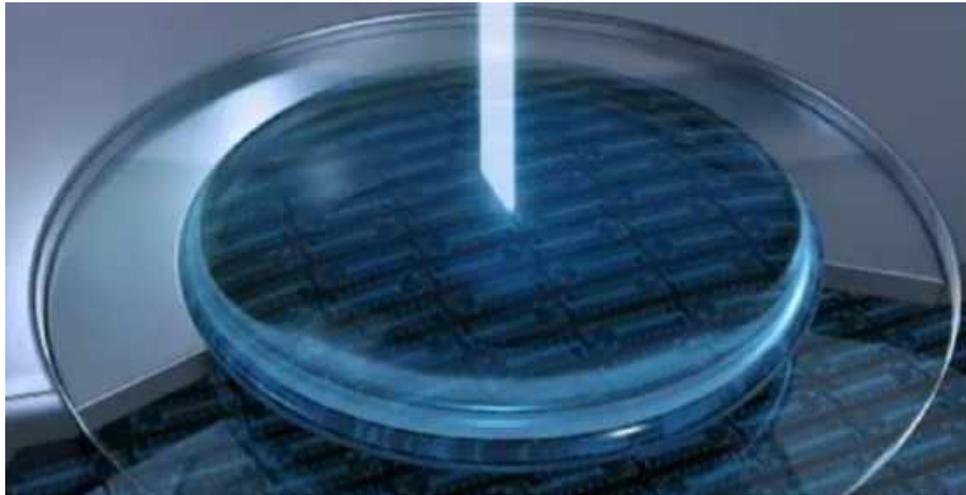
# The Required Precision



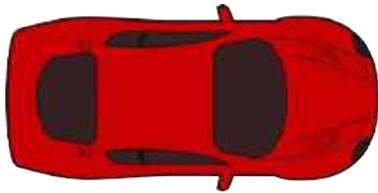
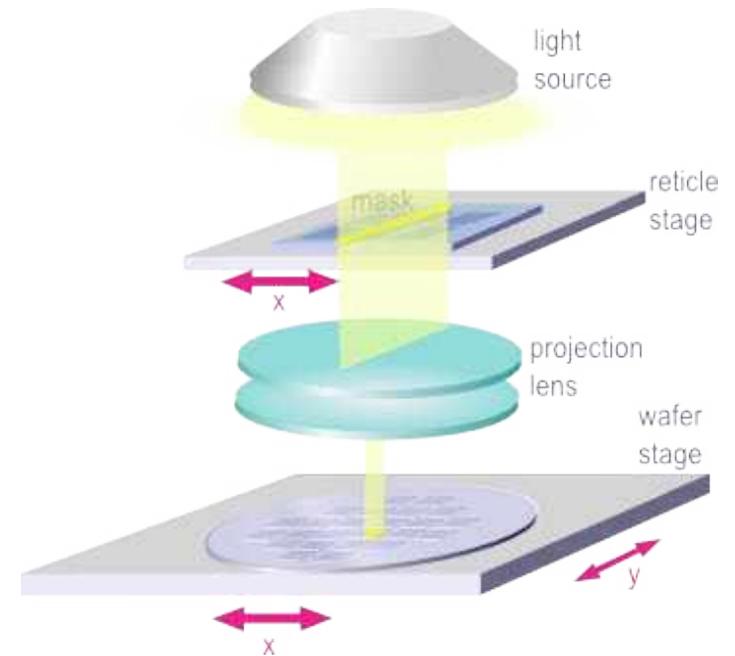
## Photolithography



# The Required Precision



## Photolithography

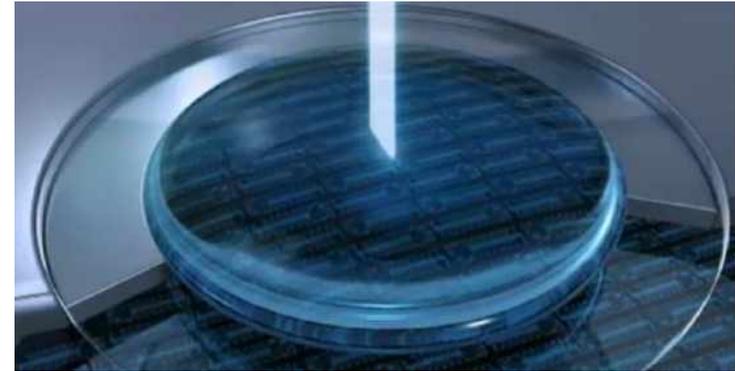
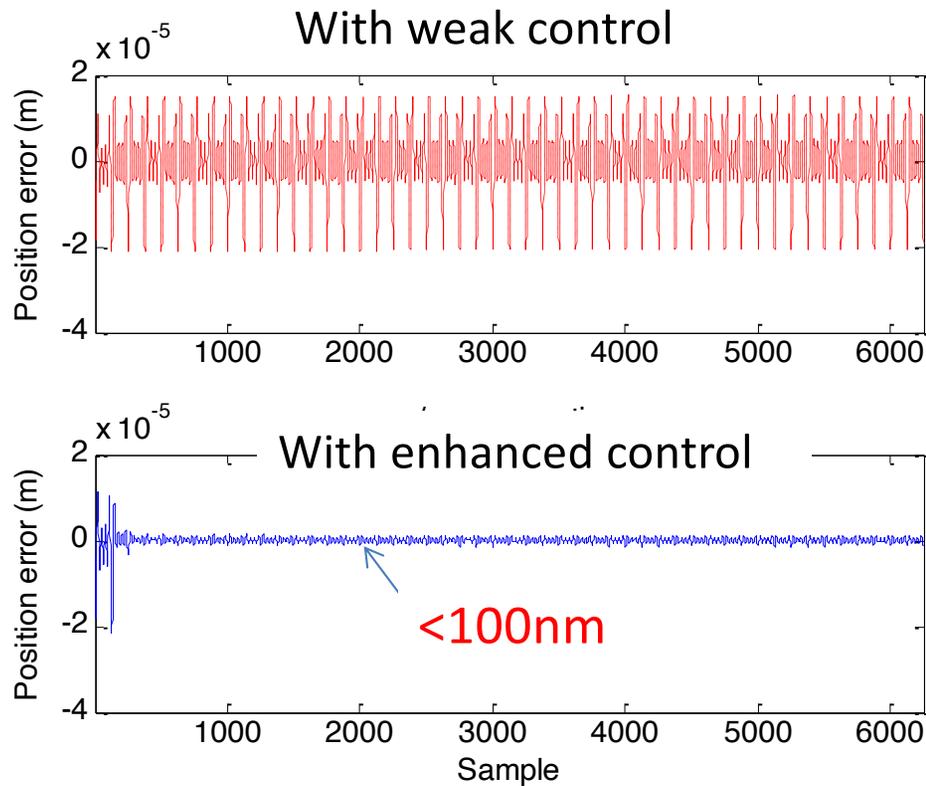


Hartford airport

mm-scale error tolerance

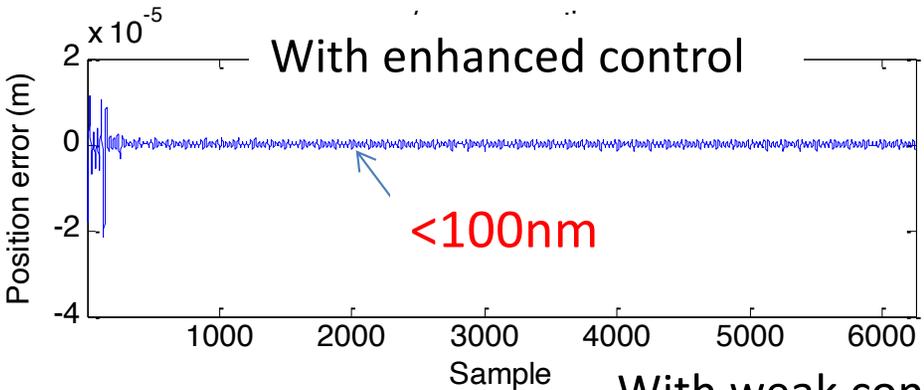
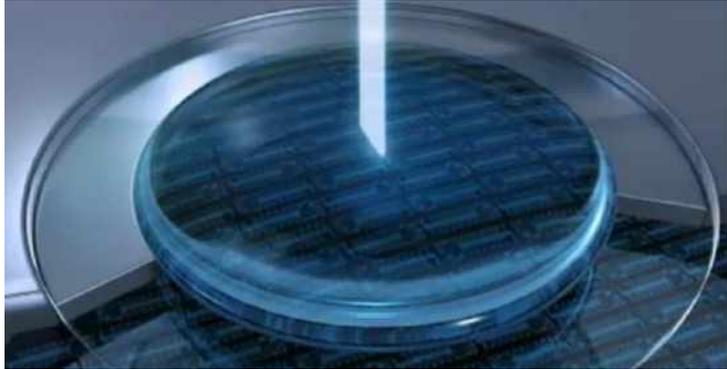
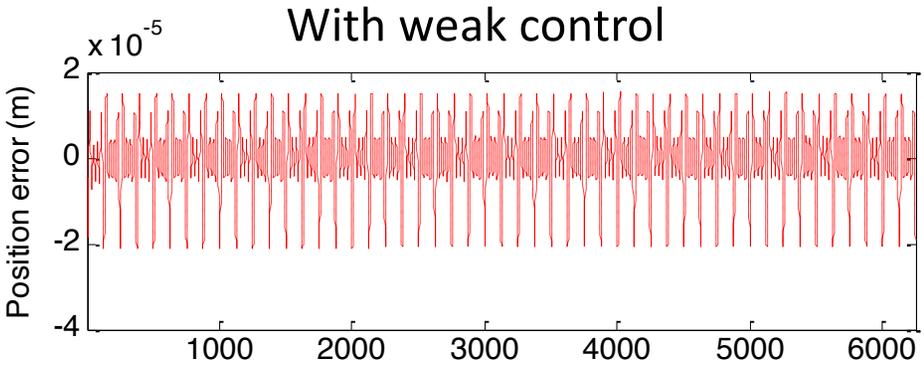
UCONN

# The Role of Automation and Controls



X. Chen and M. Tomizuka, "Control Methodologies for Precision Positioning Systems," in Proceedings of 2013 American Control Conference, Washington, DC, Jun. 17-19, 2013, pp. 3710-3717.

# The Role of Automation and Controls



With good control



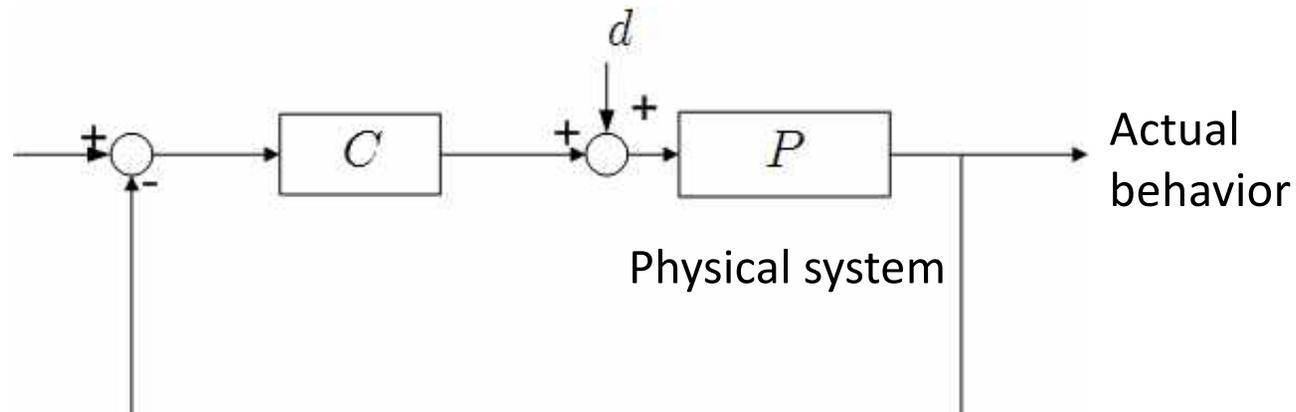
# Control Engineering

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Control engineering or control systems engineering is the engineering discipline that **applies control theory to design systems with desired behaviors.**

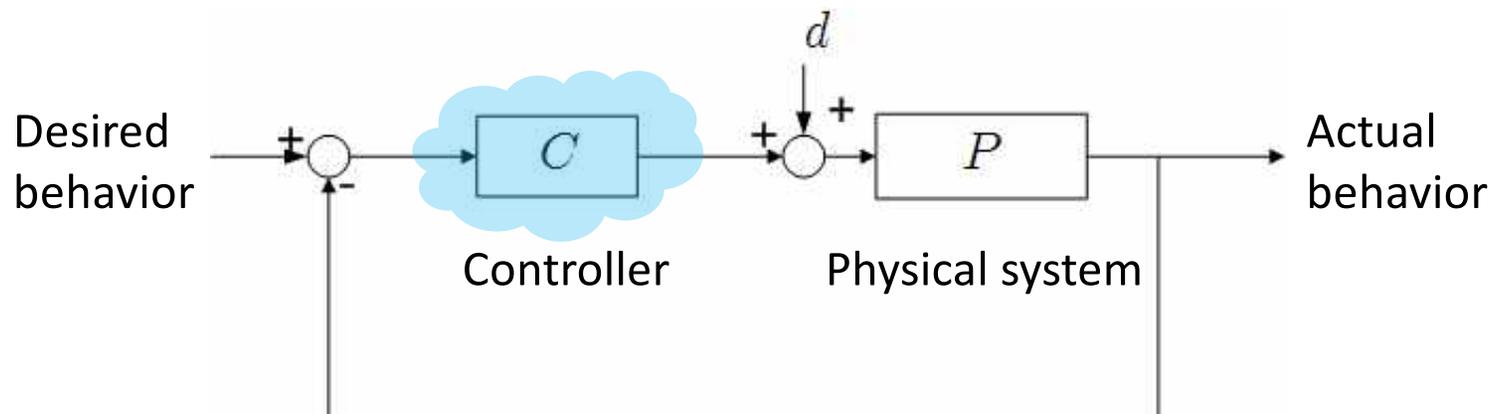
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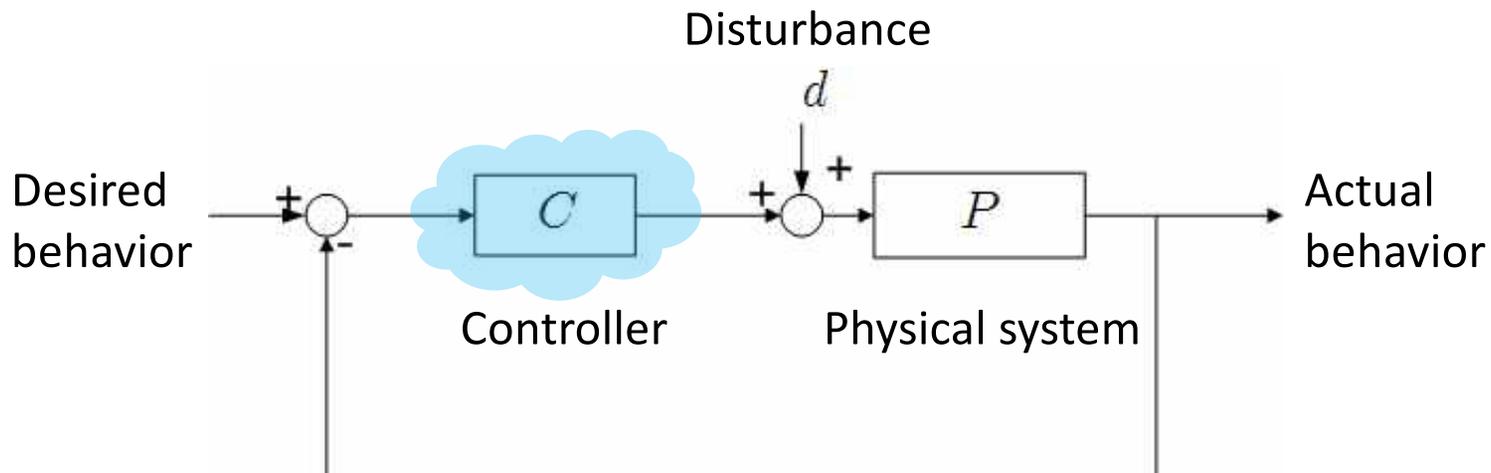
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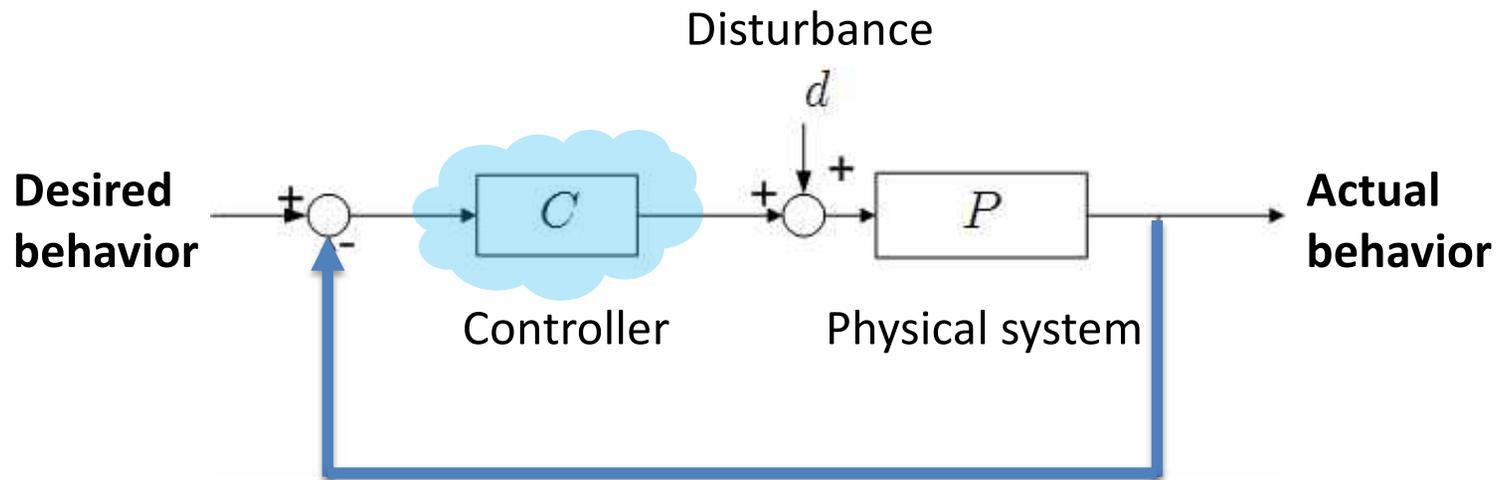
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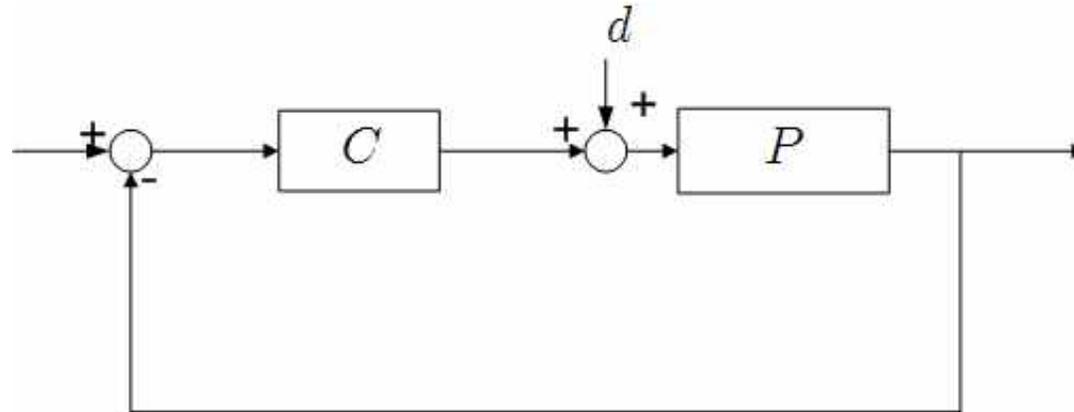


# Control Engineering

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# Why Automatic Control?



- **Stability/Safety**

- Difficult/impossible for humans to control the process or would expose humans to risk

- **Performance**

- Cannot be done “as well” by humans

- **Cost**

- Humans are more expensive and bored

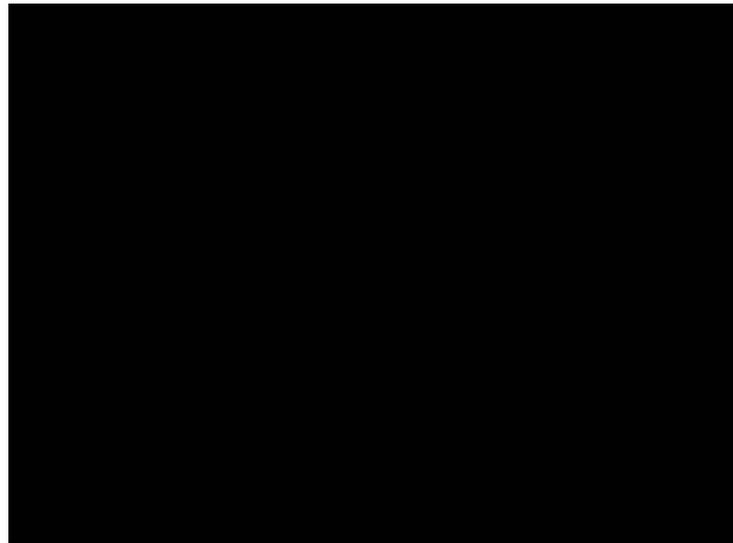
# Example of Control Systems: HDDs

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# Example of Control Systems: HDDs

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Sub-10nm  
position-error  
tolerance

# Example of Control Systems: HDDs

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# Example of Control Systems: HDDs

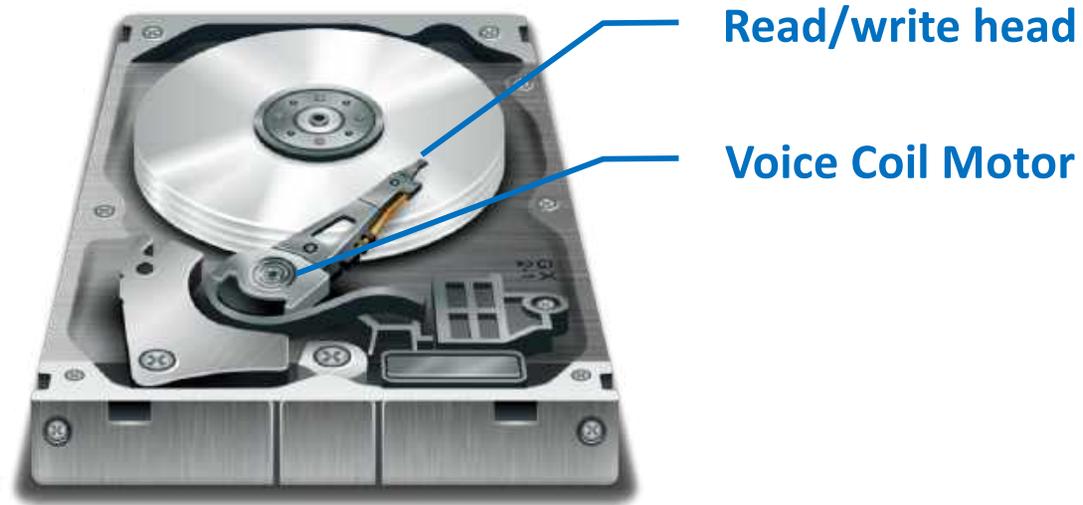
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Voice Coil Motor

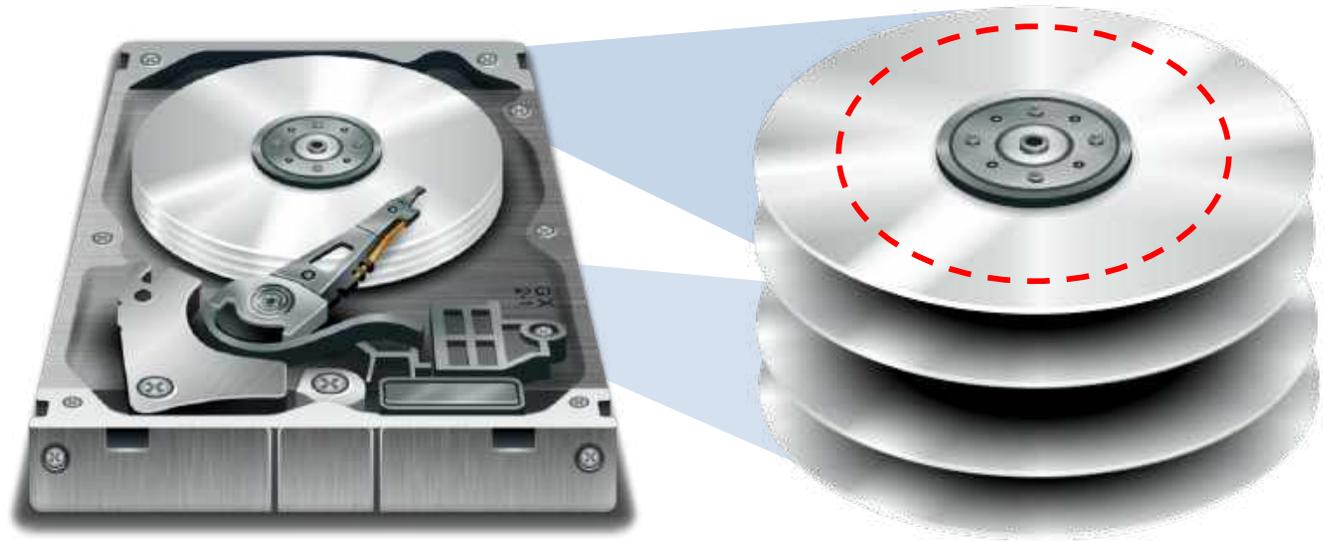
# Example of Control Systems: HDDs

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# Example of Control Systems: HDDs

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**>900,000 tracks per inch (in a 2012 HDD)**

**~ ten thousand tracks on a human hair!**

# Importance of Control Systems in HDD



Shouting in the Datacenter

1,518,607 views



7K



97



SHARE



...



**Bryan Cantrill**

Published on Dec 31, 2008

SUBSCRIBE 945

Brendan Gregg from Sun's Fishworks team makes an interesting discovery about inducing disk latency. For more details, see Brendan's blog entry: <http://blogs.sun.com/brendan/entry/un...>

# Importance of Control Systems in HDD

## A Loud Sound Just Shut Down a Bank's Data Center for 10 Hours

Dozens of hard drives were knocked down during a fire drill that involved inert gas deployment.

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TWEET



Andrada Fiscutean

Sep 11, 2016, 2:00pm



Image: [Jeff Kubina/Flickr](#).

# Recap and Outline



Semiconductor  
manufacturing



Information storage



Manufacturing  
inspection & automation



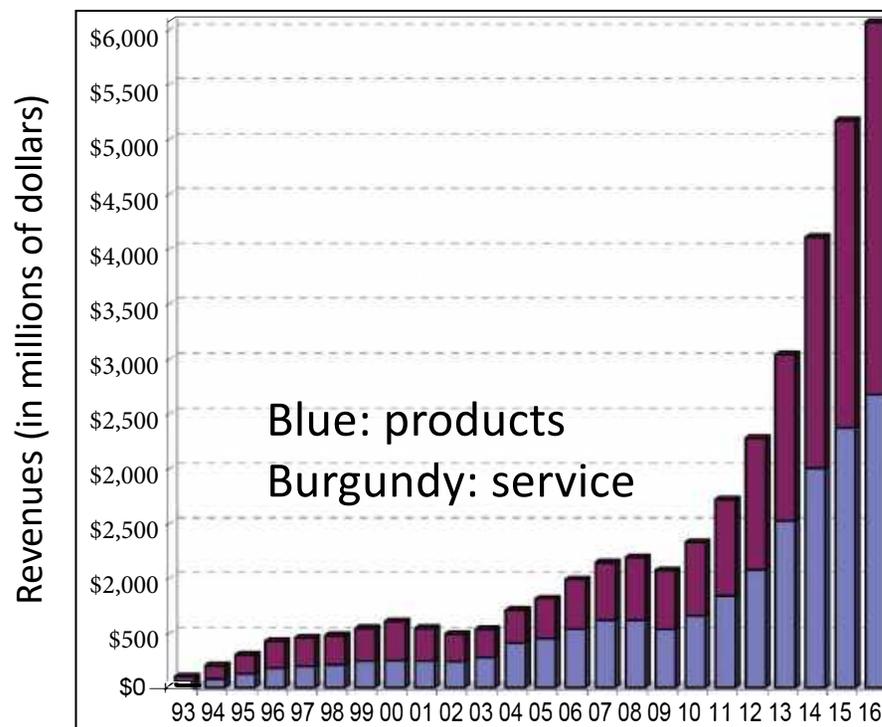
GE fuel nozzle

Additive manufacturing (3D printing)

Control engineering or control systems engineering is the engineering discipline that **applies control theory to design systems with desired behaviors.**

# Examples of Control Systems: 3D Printing

- Additive manufacturing (AM) / 3D Printing
  - Annual market recently topped \$6 billion
  - Increased nearly 6-fold over the past 7 years



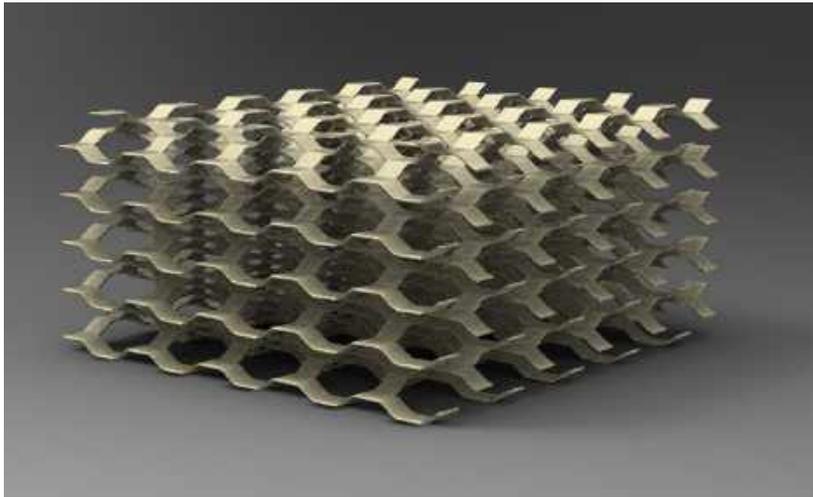
Source: Wohlers Associates, Inc.



Powder bed processes

# Background: Powder Bed Fusion (PBF)

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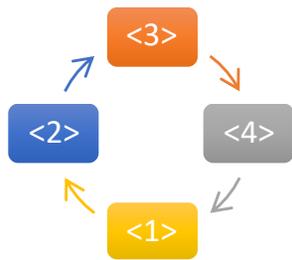
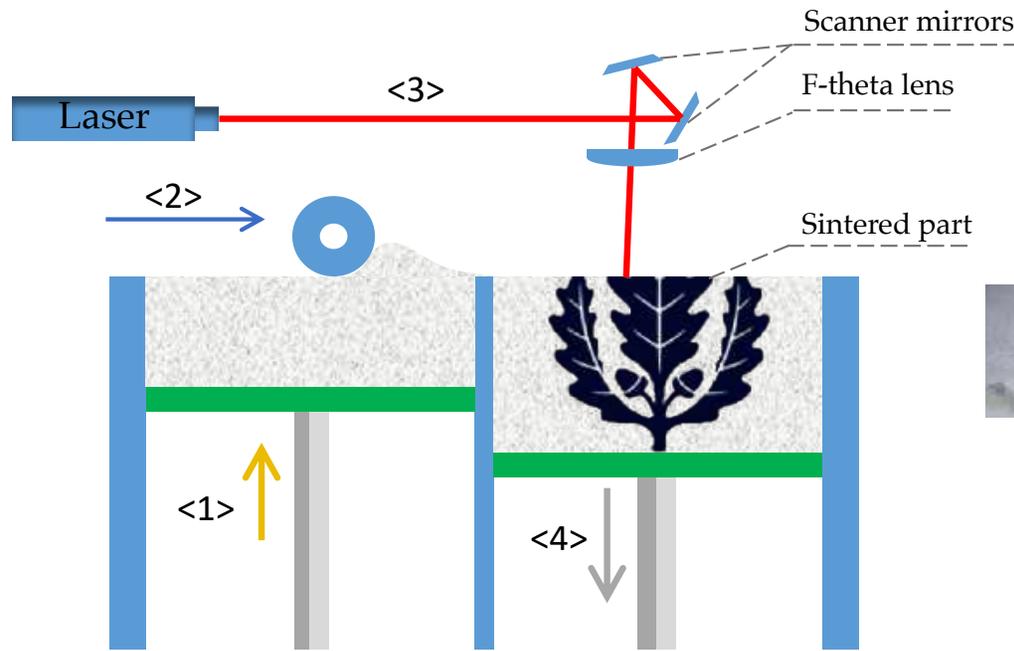


Source: UConn

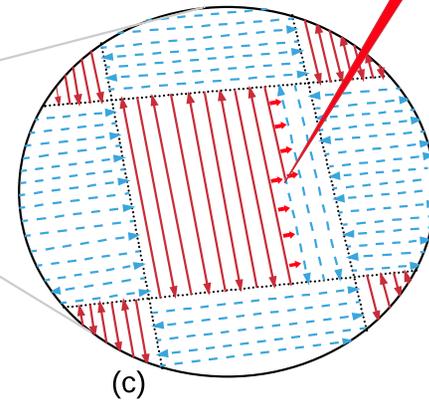
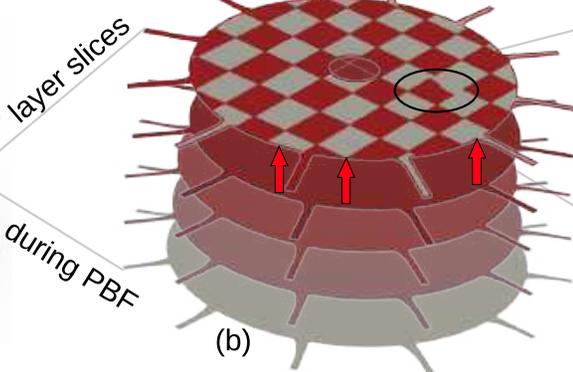
- ***Versatile***: works with a broad range of materials
- ***Effective***: high achievable shape complexity and accuracy
- ***Functional***: expanding applications from engine components to medical implants

# The Control Problem to Meet the Quality Demand

Selective laser sintering/melting:



◆ : fused materials     ↑ : direction of local heat transfer     high-power energy beam  
◆ : unfused powders



**solid line:** fused tracks.  
**dashed line:** pending tracks to scan.

- (a) part with complex geometries
- (b) cross-layer thermodynamics
- (c) in-layer precision energy deposition & thermointeractions (example: "island" raster scan)