The Future of Mechanical Ventilation Technology

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Disclaimer

- **All views expressed are my own opinion and not necessarily those of the Cleveland Clinic.**

Disclosure

- **I have affiliations with, special interests, or have conducted business with the following companies that in context with this presentation might possibly constitute a real or perceived conflict of interest: :**
  - IngMar Medical
  - Vyaire Medical
  - Timple
  - Inovytec
  - Aires
  - Ventis Medical
  - ProMedic

First
Some Stupid
Tech Predictions

3

- **Lord Kelvin-President Royal Society-1883**

"X-rays will prove to be a hoax"

4

- **Dr. Dionysius Lardner (1830)**

"rail travel not possible…passengers would die of asphyxia"

5

- **Movie producer, 20th Century Fox (1946)**

"Television won't last because people will get tired of staring at a plywood box"

6

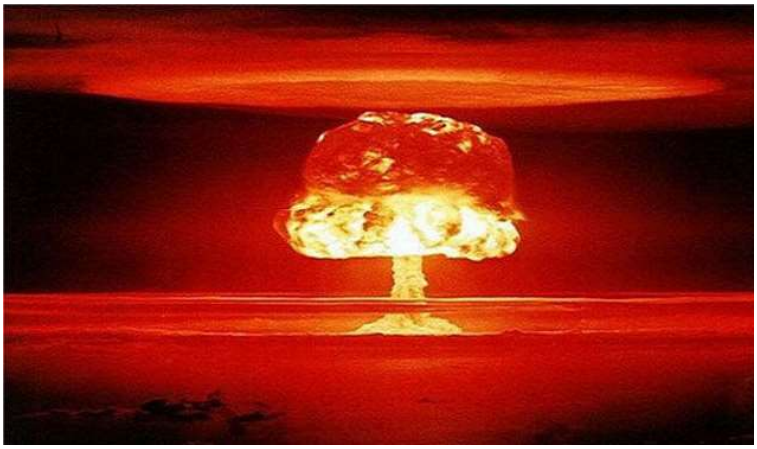
- **Chairman of IBM (1943)**

“I think there is a world market for maybe five computers”

7

- **Albert Einstein (1932)**

“There is not the slightest indication that nuclear energy will ever be obtainable”



8

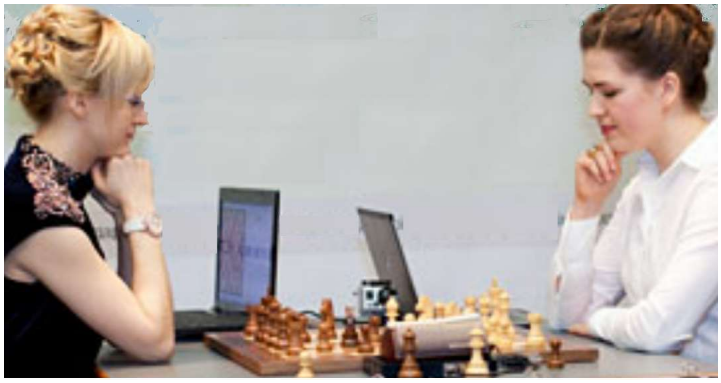
"Chess is far too complex to be definitively solved with any technology we can conceive of today." **Gary Kasparov (World Chess Champion)**

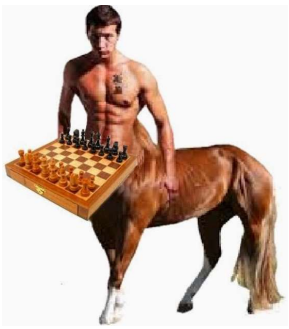
"I would have liked …a rematch in 1998 if I were better prepared, (but) it was clear then that computer superiority over humans in chess had always been just a matter of time." **Gary Kasparov (former World Chess Champion)**

9

Centaur Chess

- **Teaming computers with humans, produces a force that plays better chess than either humans or computers can manage on their own**





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Context
Brief history of mechanical ventilation

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History of Resuscitation

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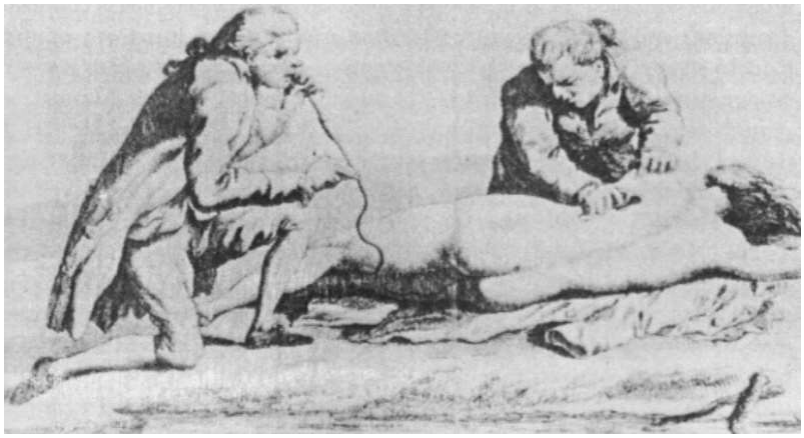
Origin of the term “blowing smoke”???



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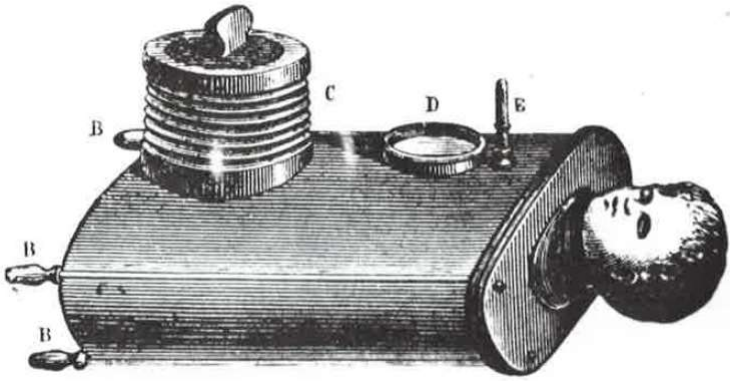
Woillez’s Spirophore (1876)



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Cleveland Respirator

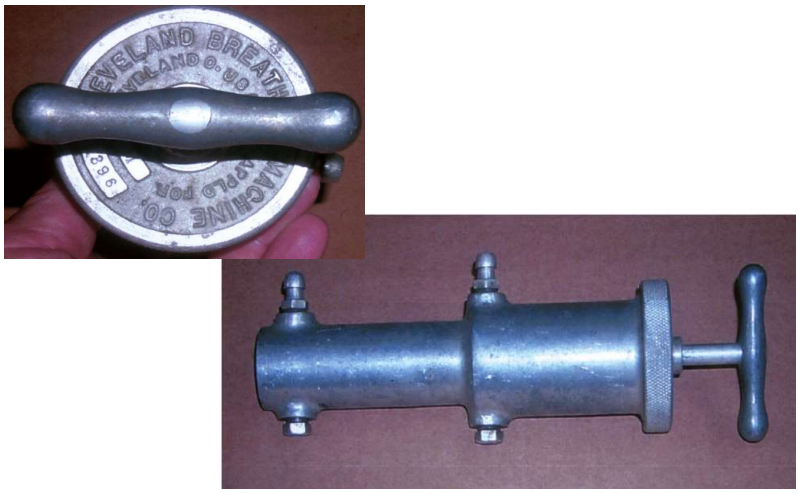

photo courtesy of Rich Branson

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Dräger Pulmotor (Germany 1907)

Heinreich Dräger

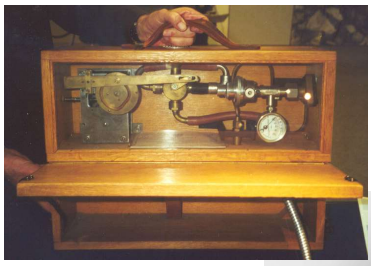

photo courtesy of Rich Branson

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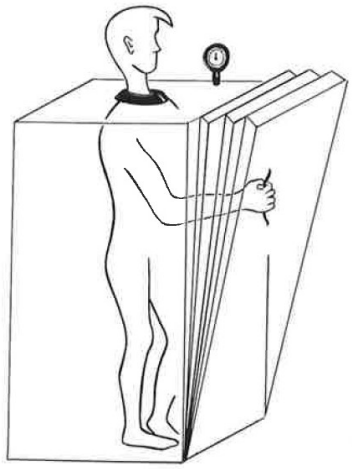
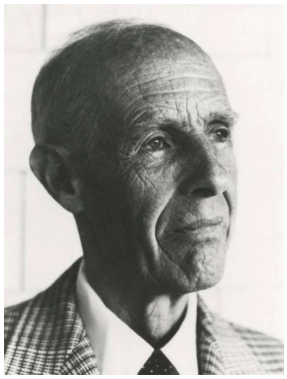
Wilhelm Schwake Germany (1926)



- Designed to improve synchrony
- "Negative pressure on the skin pulls out gaseous by-products"

17

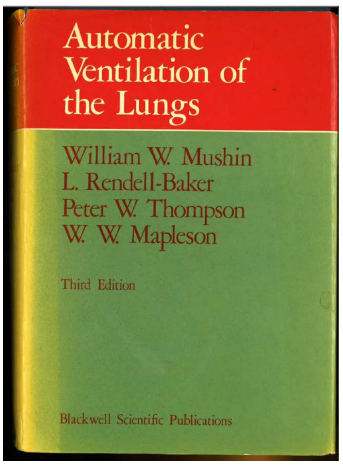
John Haven "Jack" Emerson (USA 2/5/1906 – 2/4/1997)



Pioneer of tank and piston ventilators

18

Original Bible of Mechanical Ventilation

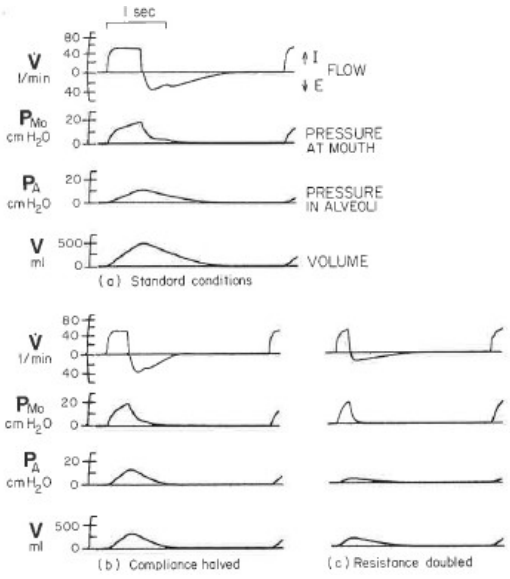


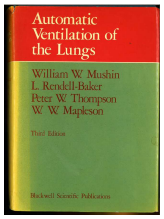
London 1959

All Anesthesiologists

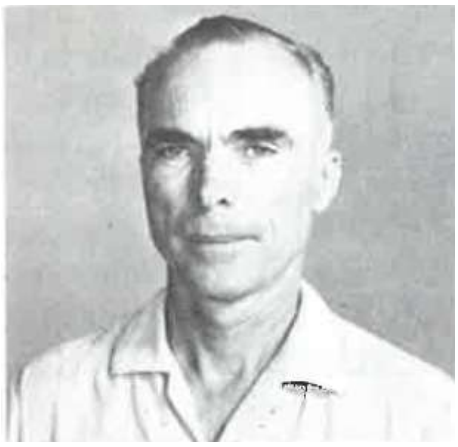
Detailed descriptions of 74 ventilators!

Simulator-Based Waveforms

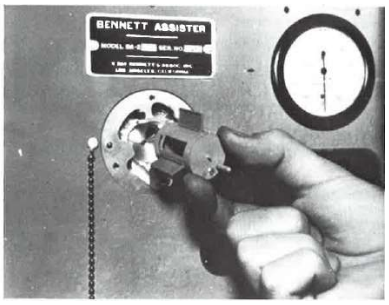




Ray Bennett, USAF (1970)



Flow control valve (1947)



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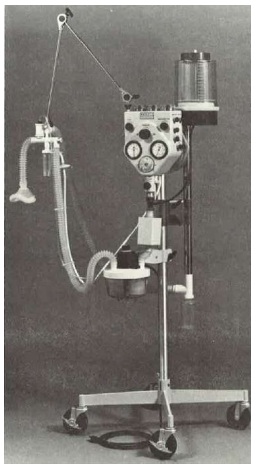
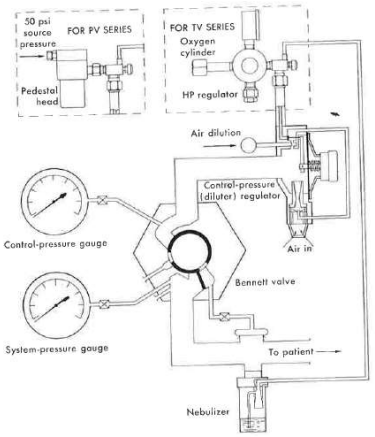
PR Series Ventilators (1948-1990s)





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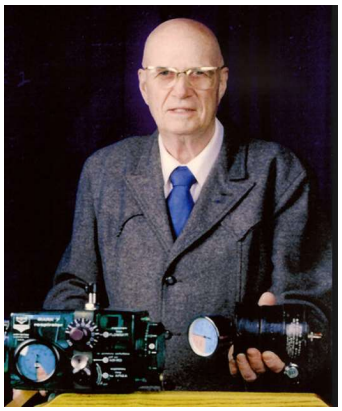
Dr. Forest Bird (1958)



Magnets and clutch plates

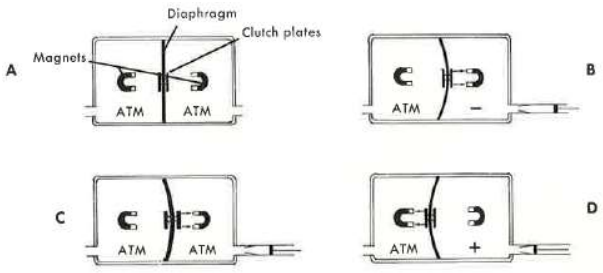


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photo courtesy of Rich Branson

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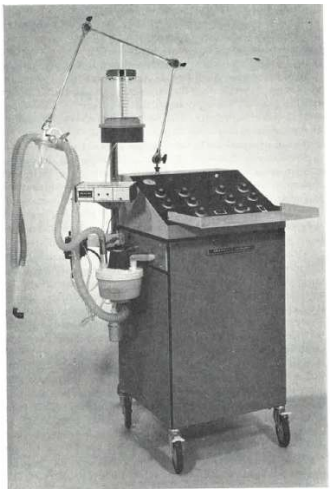
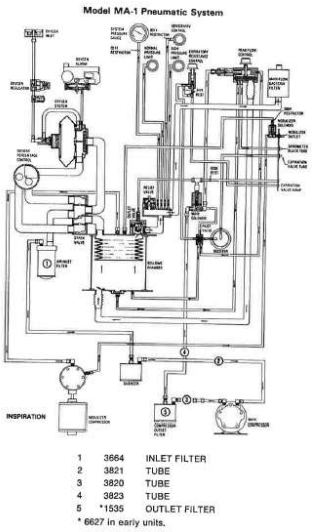
Bennett MA-1 (USA 1970s)





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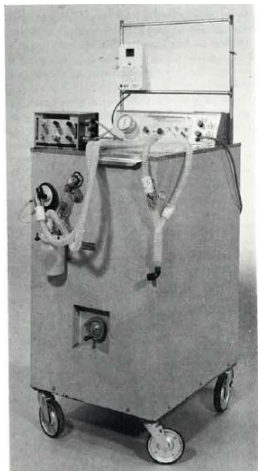
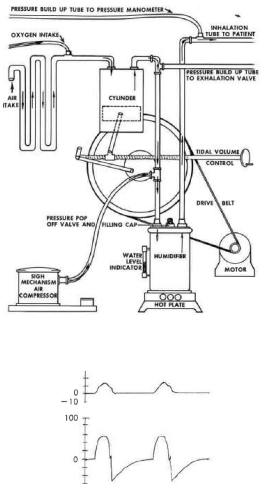
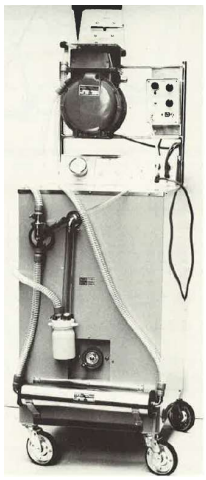
Emerson Post-Op and 3-PV (USA 1970s)







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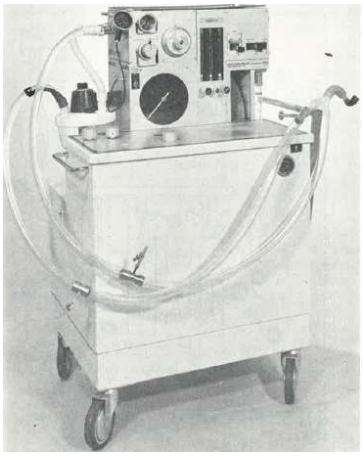
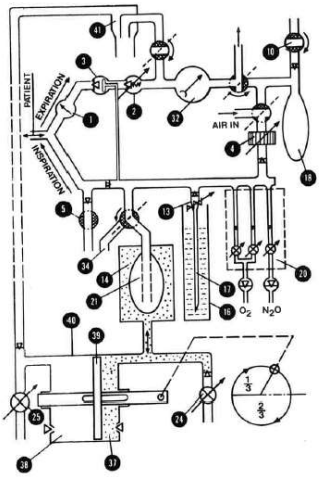
Engström (Denmark 1970s)





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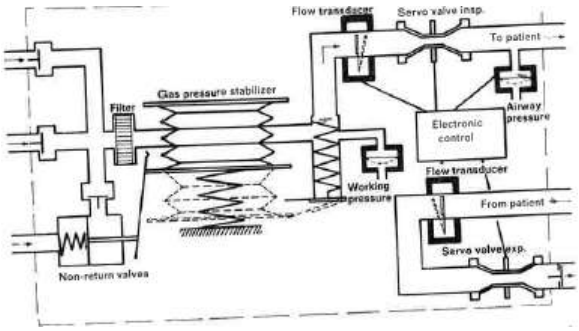
Servo 900 series Sweden (1970s)



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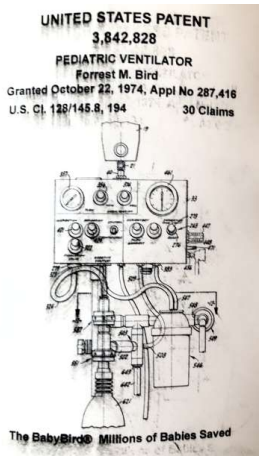
First US Infant Ventilator (1974)

Dr. Forrest Bird

patent courtesy of Felix Khusid



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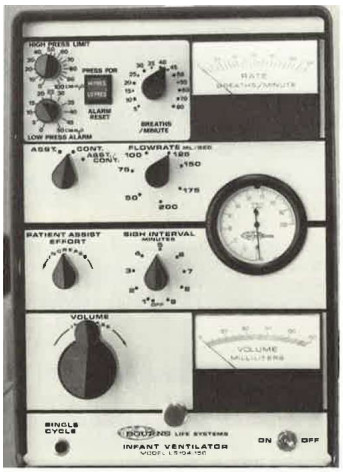
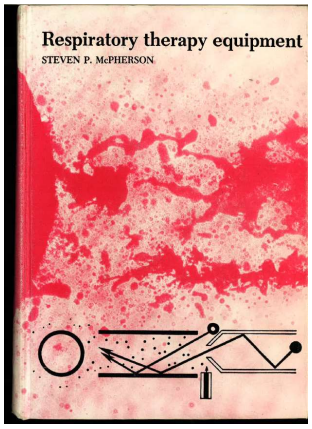
First with mode selection? (infant ventilator 1980s)

1. Assist
2. Control
3. Assist/Control



The First RT Equipment Book (1977)



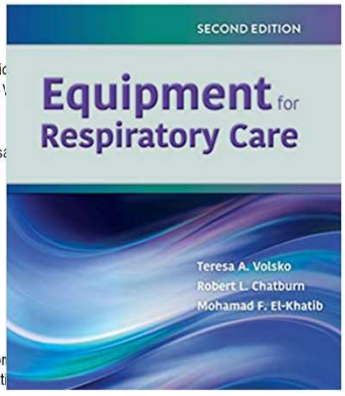
Respiratory therapist author

Detailed descriptions of 31 ventilators

Only mentions 3 modes!

Most Recent RC Equipment Book (2021)

AC PCV
Adaptive Flow
Adaptive Support Ventilatic
Airway Pressure Release
APV SIMV
Assist/Control
Automatic Tube Compensa
Automode (PRVC-VS)
AutoMode(VC-VS)
BiLevel
BiPAP S/T
CMV
CMV+AutoFlow
CMV+Pressure Limited
CPAP
DuoPAP
Flow Adaptive Volume Cor
Mandatory Minute Ventilat
PC-A/C
PCV+



500 mode names
In United States alone

Terry Volsko

Mohamad El Khatib

Rob Chatburn

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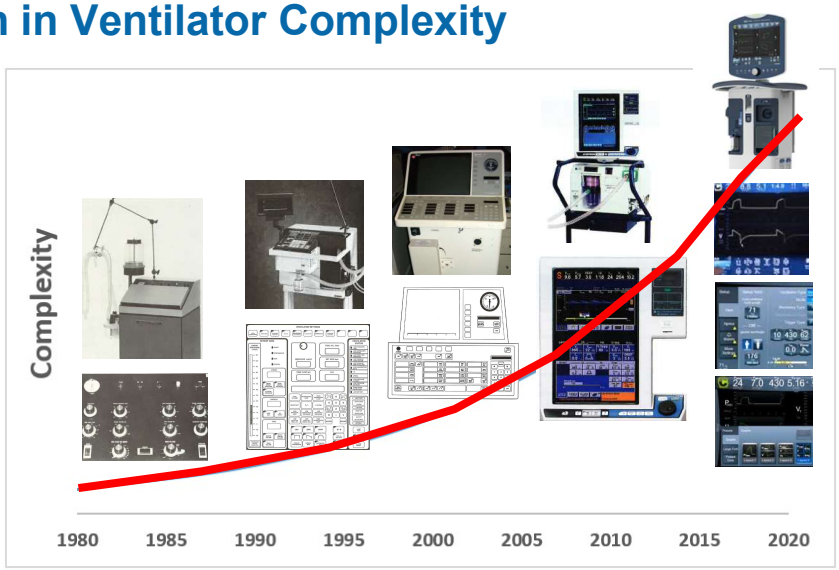
Growth in Ventilator Complexity



2nd gen 3rd gen 4th gen 5th gen 6th gen

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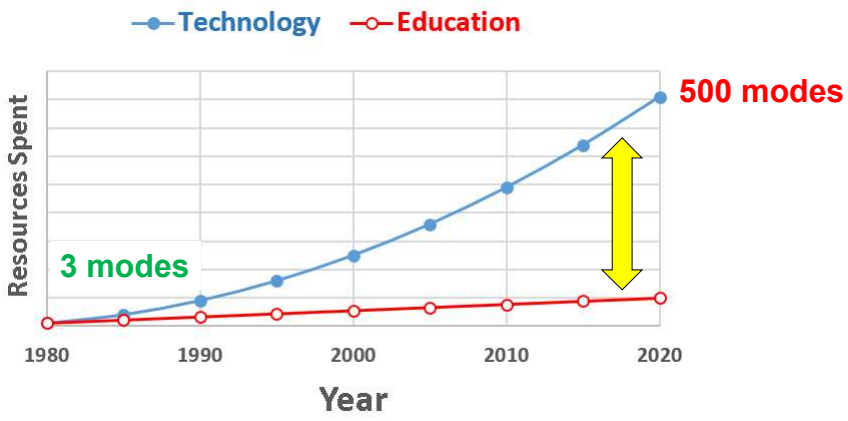
Growing Knowledge Gap



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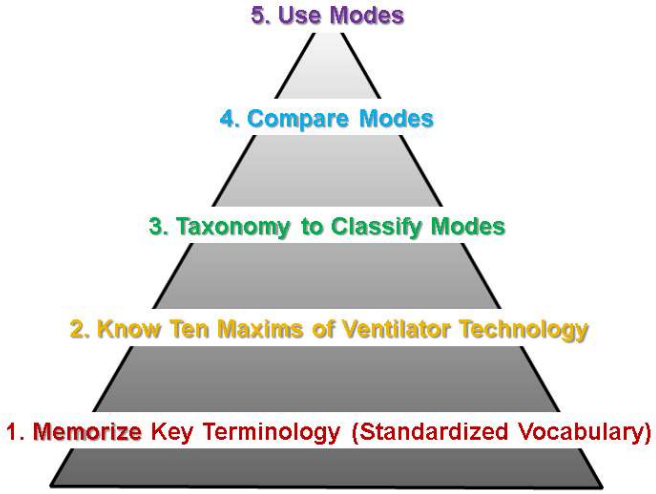
Hierarchy of Skills



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Problem

How do we deal with the technical complexity of mechanical ventilation?

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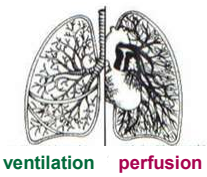
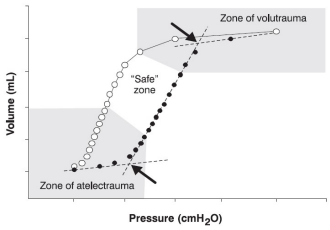
What Are the Goals of Ventilation?

1. **Do no harm (promote safety)**
   - Provide adequate gas exchange
     - *Optimize V/Q relation*
   - Protect the lung
     - *Optimize P/V relation*
2. **Promote patient comfort**
   - *Optimize WOB_{vent} vs $WOB_{patient}$*
3. **Liberate as soon as possible**
   - *Optimize weaning experience*





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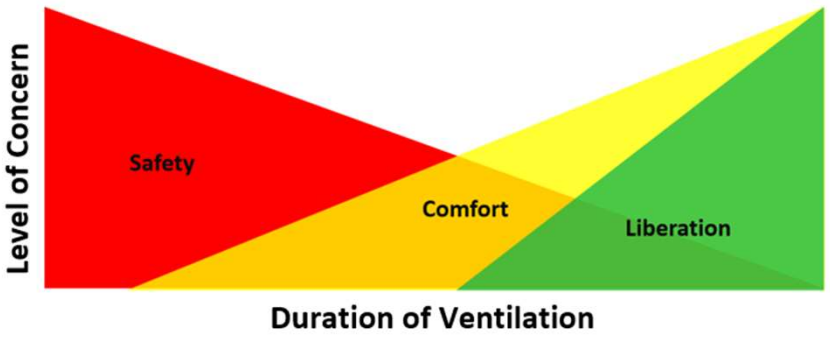
Key: Only One Goal Prevails at a Time



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Taxonomy for Modes of Ventilation

- **Mode: a pre-determined pattern of patient-ventilator interaction**
- **Mode name: arbitrary name assigned by manufacturer**
- **Mode tag: classification (generic name)**
  1. Control variable (pressure or volume)
  2. Breath sequence (CMV, IMV, CSV)
  3. Targeting scheme

PMID: 25118309

1. Set-Point
2. Dual

Manual

3. Servo
4. Bio-Variable
5. Adaptive
6. Optimal
7. Intelligent

Automatic

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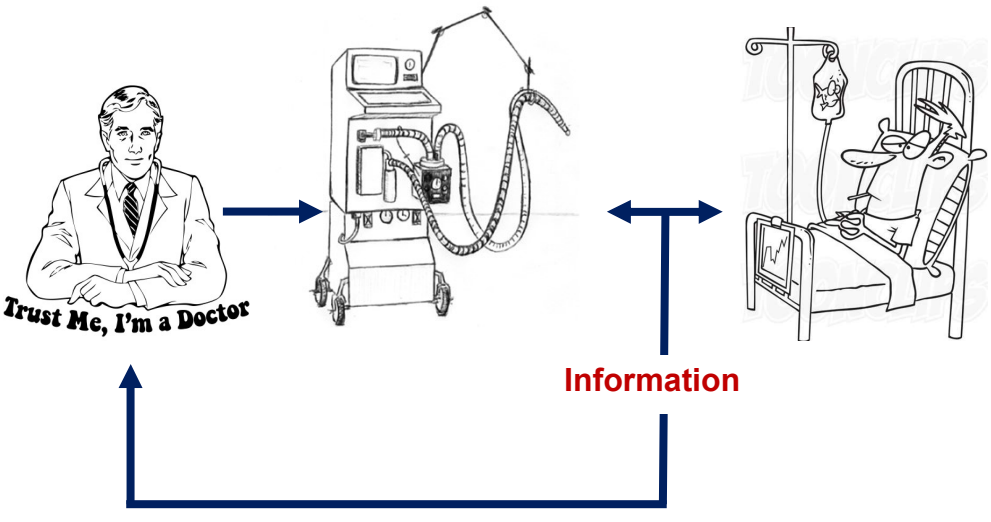
Current Paradigm (Human Control)



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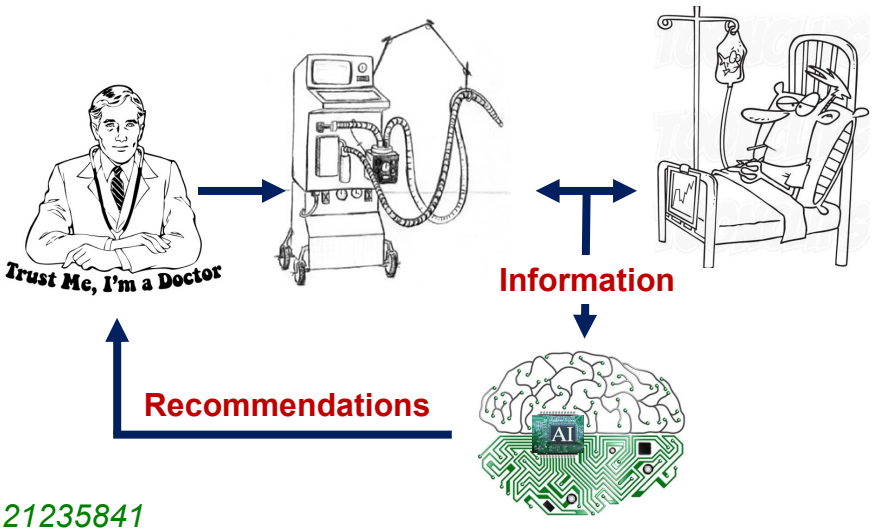
Open Loop Control (Decision Support)



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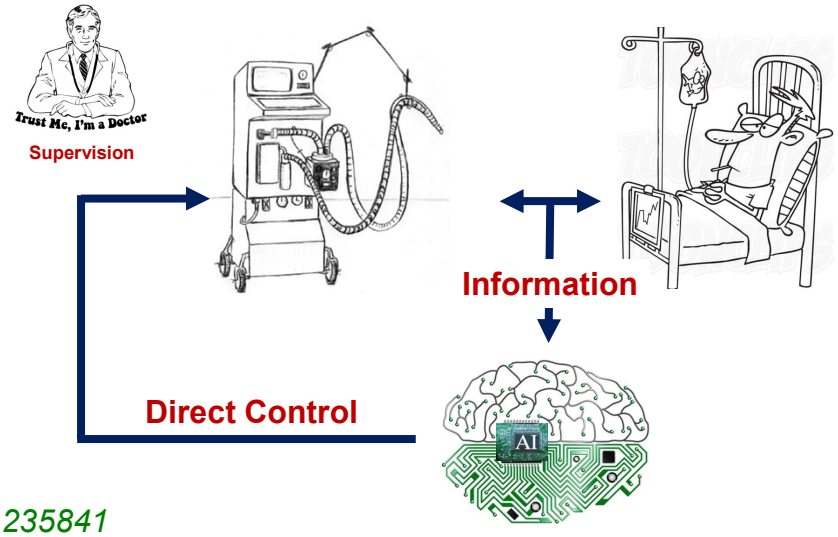
Closed Loop Control



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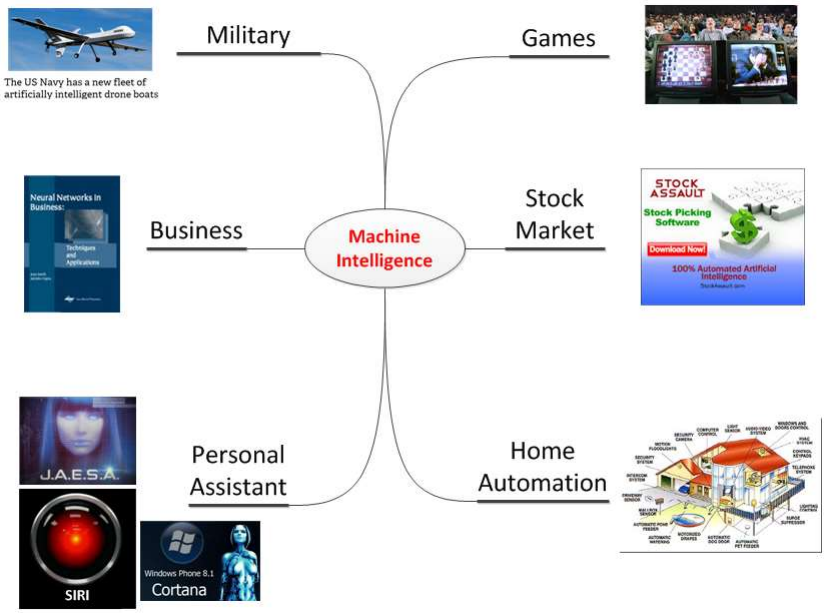

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Popular Science June 2015

- **30,000 people die yearly in US auto accidents**
  - —> 1,000,000 injured
- **With self-driving cars, decision making will no longer exist in real time.**
- **Decision making will shift**
  - —From a driver sitting behind the wheel
  - —To teams of designers sitting behind computers anticipating crash situations
- **Cars will be networked and learn from each other**

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Implications
What will the future bring to mechanical ventilation?

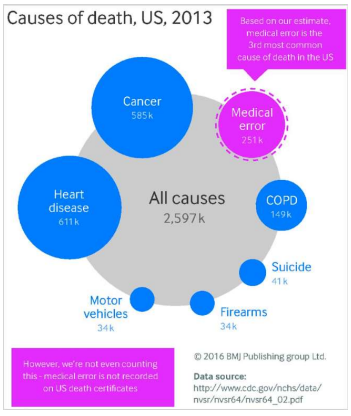
45

Closed-Loop Ventilation: An Emerging Standard of Care?

Wysocki, Brunner. Crit Care Clin 2007;23:223-240

Arguments for Automation of Mechanical Ventilation

- **Medical Errors**
  - Up to 400,000 patients die annually due to errors
  - Equivalent to 4 plane crashes per day
  - 3rd most common cause of death



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Intelligent Targeting Schemes

- **Automatic adjustment using artificial intelligence tools**
  - Mathematical models of physiologic systems
  - Rule based expert systems
  - Fuzzy logic
  - Artificial neural networks

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The Computer of the Future

https://www.youtube.com/watch?v=Yg75XeZGQS0

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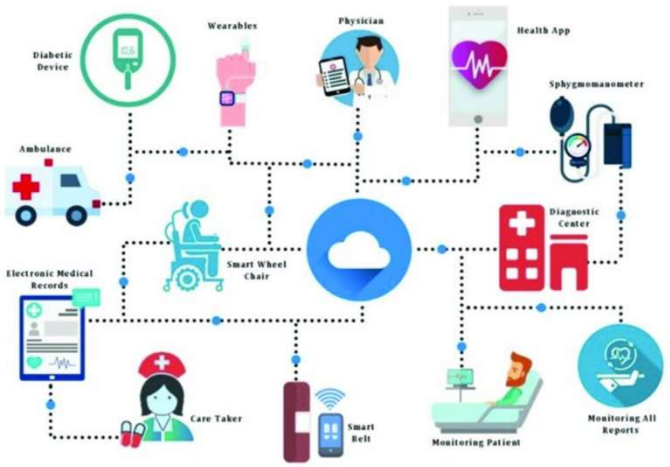
The Internet of Medical Things



https://www.researchgate.net/publication/340567486_Mining_Massive_E-Health_Data_Streams_for_IoMT_Enabled_Healthcare_Systems

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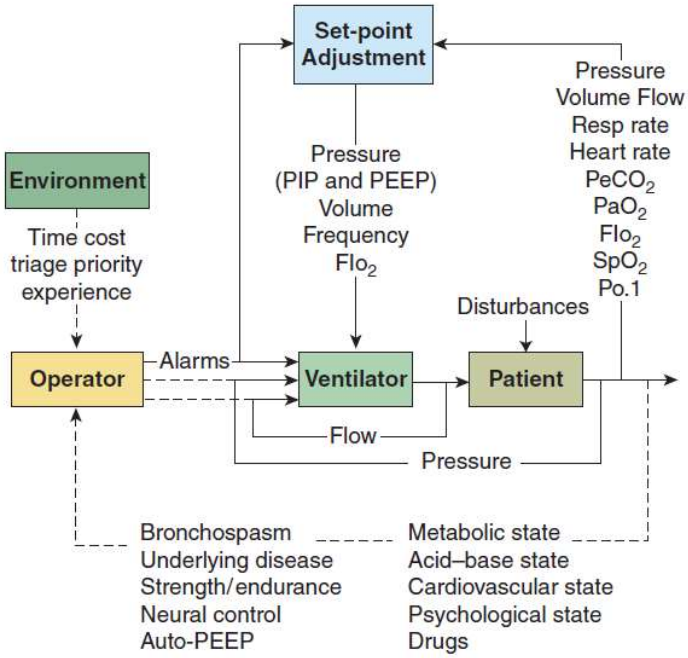
The Challenge of Total Computer Control



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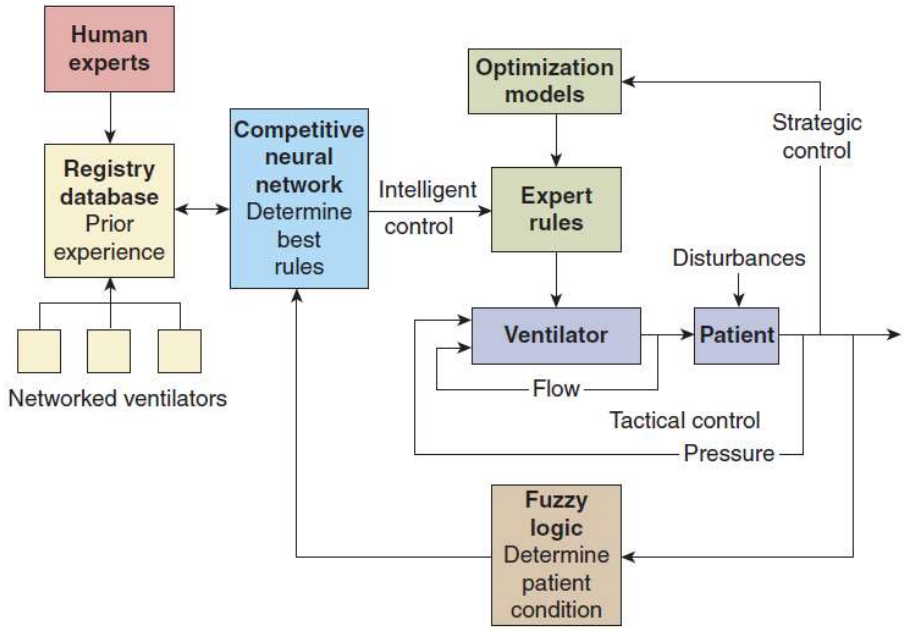
The Ventilator of the Future (black box)



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Ventilator Artificial Intelligence Becomes Self-Aware

The Termilator

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