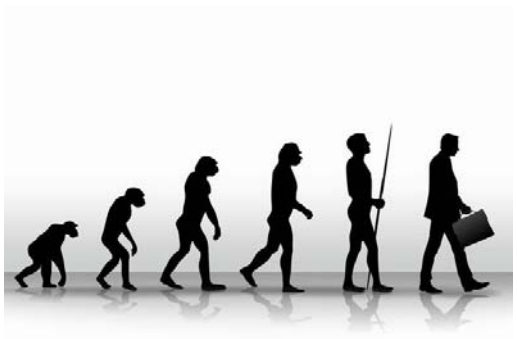
Evolution Theory of Ink Jet Technologies

- Progress by Component or Architectural Knowledge



Masahiko FUJII

Inkcube

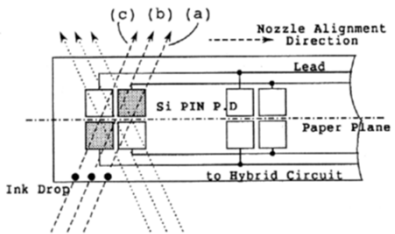
Marking Technology Laboratory
Fuji Xerox Co., Ltd.

Involvement in Ink Jet

FUJI XEROX

1985 1990 2004 / 2005 2008 2017

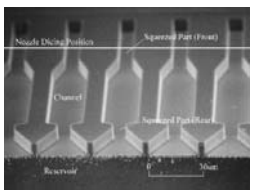
Continuous Ink Jet



Single Drop Detector

M. Fujii, Optical Drop Sensor of Continuous Ink Jet Printer, 19th Imaging Technology Conference, 1988

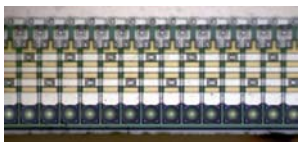
Thermal Ink Jet



800dpi MEMS Printhead

M. Fujii, New Thermal Ink Jet Printhead with Improved Energy Efficiency Using Silicon Reactive Ion Etching, The Journal of Imaging Science and Technology, Vol. 43, No. 4, 1999

Applications of Ink Jet



Micro-Lens Array

M. Fujii, Issues and Approaches Imposed on Ink Jet for The Progress of Printed Electronics, Transactions on The Japan Institute of Electronics Packaging Vol. 3, No. 1, 2010

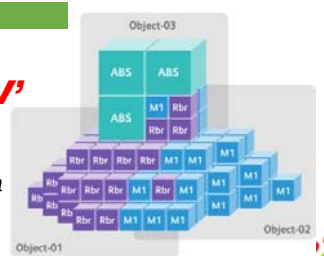
3D Printing

High Quality 3D Printer

3D Data Handling

Voxel-Based 3D Data Format 'FAV'

T. Takahashi & M. Fujii, Unrestricted 3D Structure Modeling and Seamless Data Flow to 3D Printers Using Voxel-based Data Format FAV (Fab-able Voxel), IS&T's NIP32, 2016



Macro-Trend of Ink Jet Printer

Next Year (2018) :

The 50th Anniversary of The First Ink Jet Printer Appearance

And The 80th Anniversary of C. F. Carlson's Experiment for EP

- Pagewide Printhead
- R2R
- Fast Drying Ink
- Dryer

2005

True Press Jet 520 (Screen)

2011

2017

High Image Quality

&

High Speed

2003

High Speed

1984

ThinkJet (HP)

1996

High Image Quality

Small Size

Mingograph (Siemens)

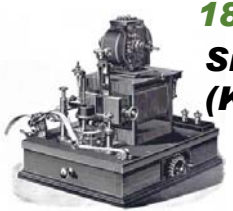
1938

1952

1968

Videojet (A.B.Dick)

1876



Siphon Recorder (Kelvin)

PM-700C (EPSON)

- Diluted Ink
- Photo Paper
- Small Drop

JetPress 720 (Fuji Film)

- Defect Detection & Correction
- Impression Cylinder
- Under-Coating
- Latex Ink
- Dryer

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Definition of Ink Jet

(My) Definition of Ink Jet :

Dropletize liquid including colorants or functional materials,

and

Eject drops to recording target (media) on demand from image (pattern) signal,

then

Bring colorants or functional materials to (on) recording target (media).

- ✓ **Defining technology is important to identify the invention, and to consider extensions or applications of the technology.**
- ✓ **Ink Jet is not a technology only to realize printers.**

M. Fujii, S. Sakai, A. Tomotake, H. Eguchi etc. (2008)

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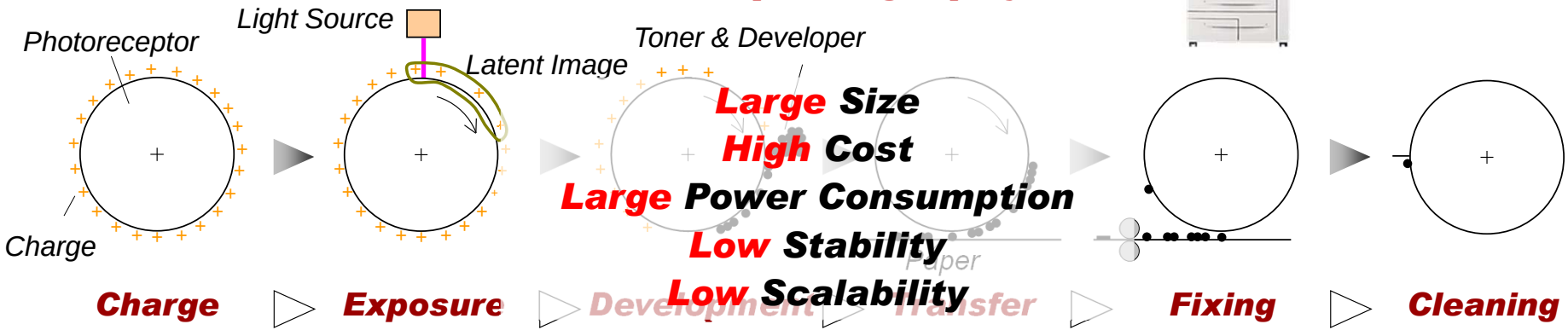
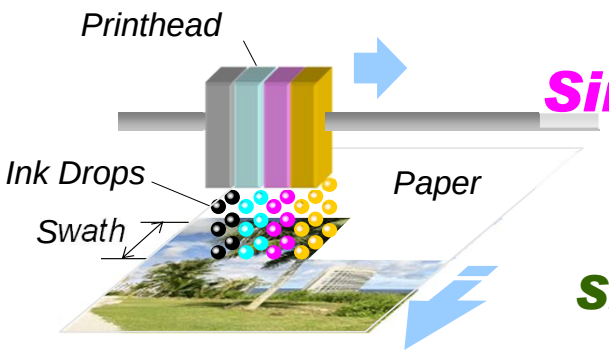
Marking Process of EP & Ink Jet

Electrophotography



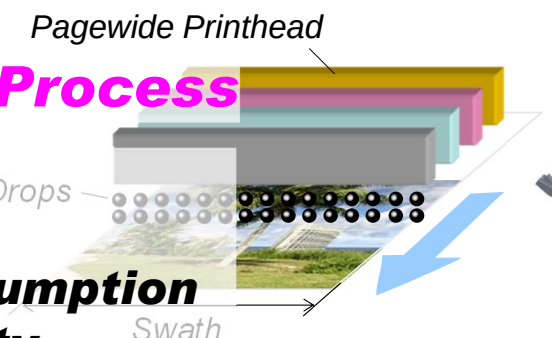
Large Size
High Cost
Large Power Consumption
Low Stability
Low Scalability

Ink Jet



Simple Marking Process

Small Size
Low Cost
Small Power Consumption
High Stability
High Scalability



Serial Printer

Line Printer

Possibility & Limitation of Ink Jet

Ink Jet Marking Process is Simple.

- ✓ **Simplicity of process has both aspect of a possibility and a limitation.**
- ✓ **These two aspects led me my ink jet evolution theory.**

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Concentrating Functions Progress (CFP)

Simple Process

Circumjacent Technologies

Ink Supply

Maintenance System

Image Processing Dot Placement

Key Components

- Printhead
- Ink (Functional Liquid)
- Paper (Media)

Printer's Prime Performances

Image Quality	Print Speed
Drop Volume	Firing Frequency
Nozzle Resolution	Nozzle Number
Ink Latitude	Robustness
Directionality	
Penetrability	Penetrability
Multi-Color	
Color Reproduction	
Absorbability	Absorption Speed
Circularity	
Gloss Control	

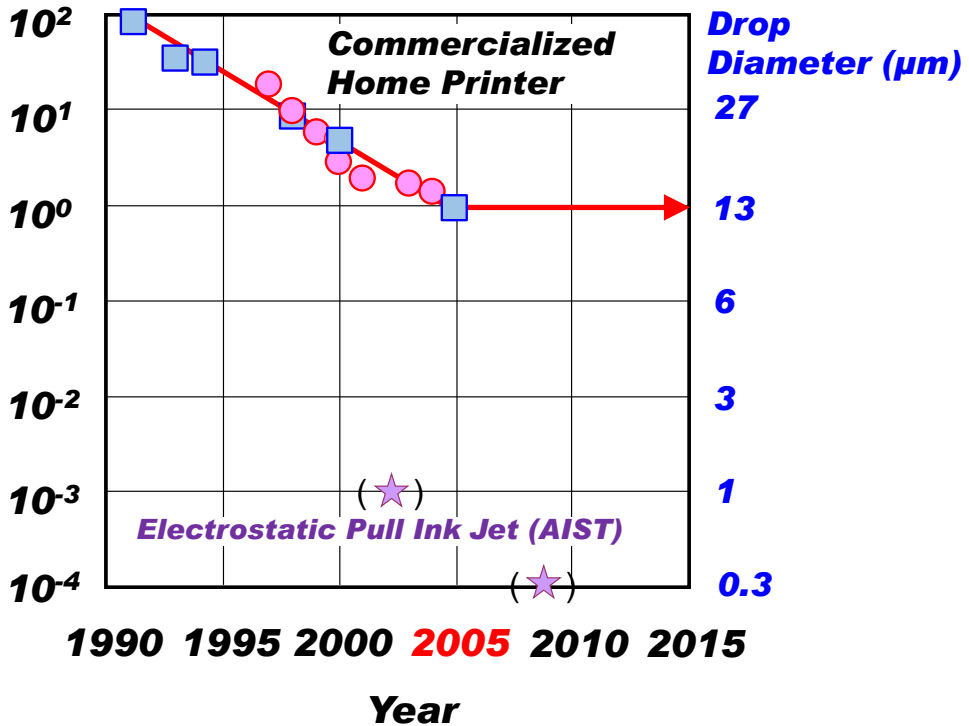
Concentrating Functions Progress (CFP)

Progress of system performance has been brought by progress of each key components performance

Keeping merits come from process simplicity of Ink Jet

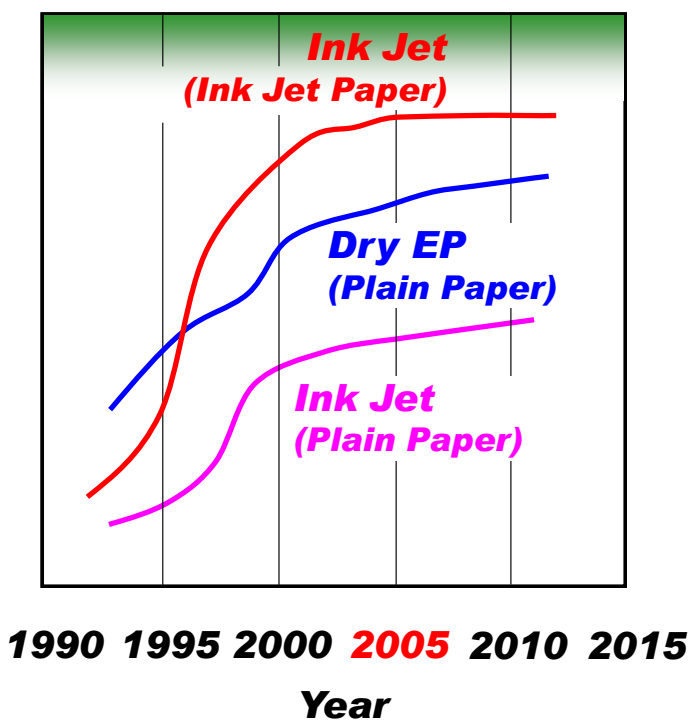
Drop Volume & Image Quality

Minimum Ink Drop Volume (pl)



(Image Quality Quantified from Visual Aspect)

Sensory Evaluation Score for Image Quality



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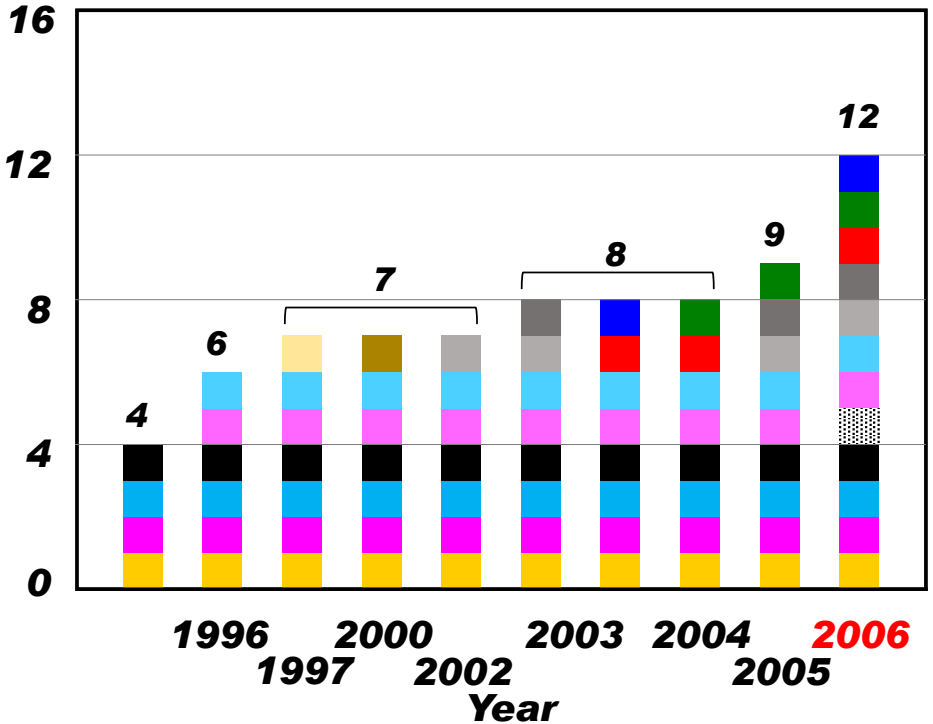
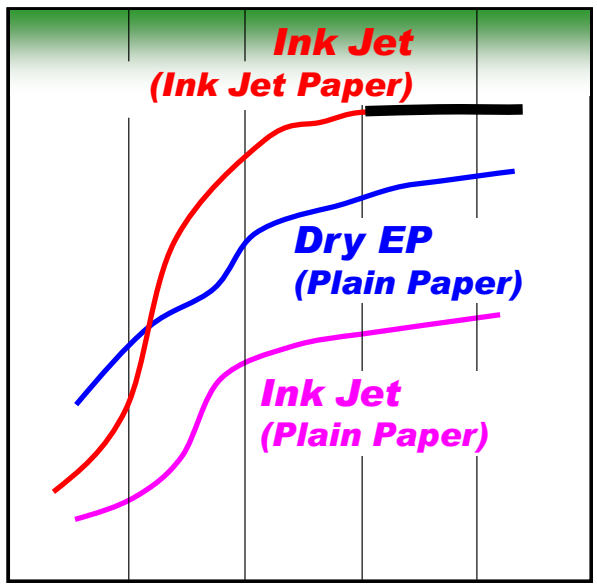
Drop Volume & Image Quality

Number of Ink Color



(Image Quality Quantified from Visual Aspect)

Sensory Evaluation Score for Image Quality



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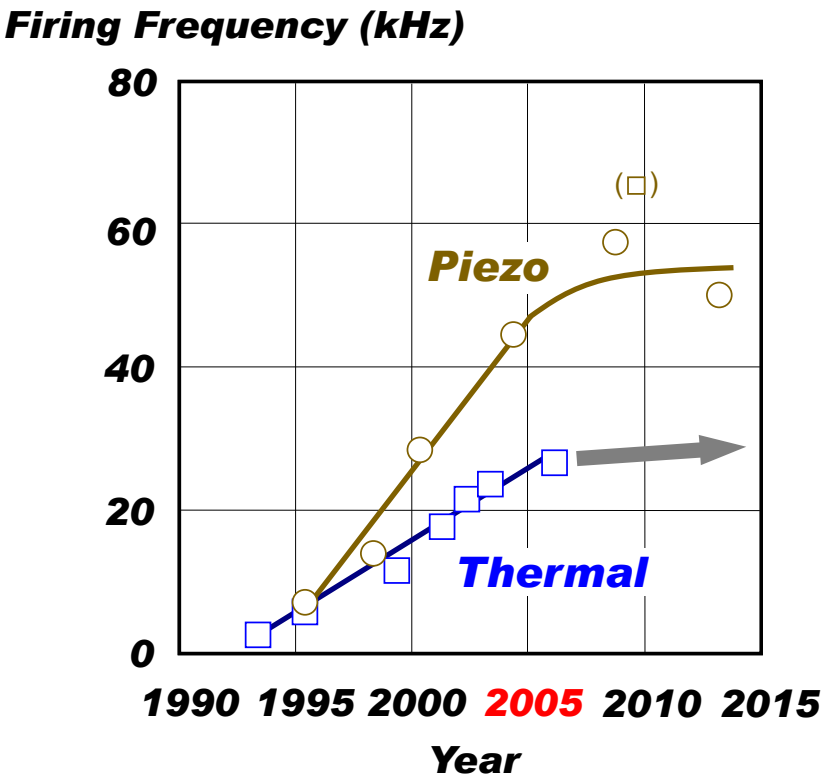
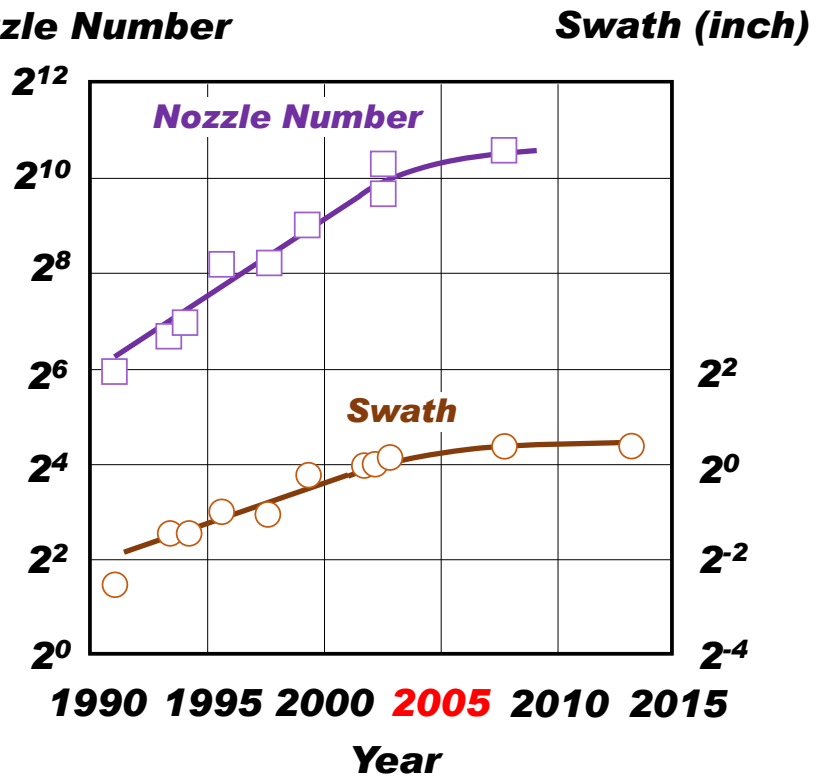
Speed Factor (Print Speed)

$$\text{Speed Factor} = \frac{\text{Frequency} * \overbrace{\text{Nozzle Number}}^{\text{Swath}}}{\text{Multi-Path} * \text{Resolution} * \text{Print Direction}} - \text{Maintenance} - \text{Others}$$





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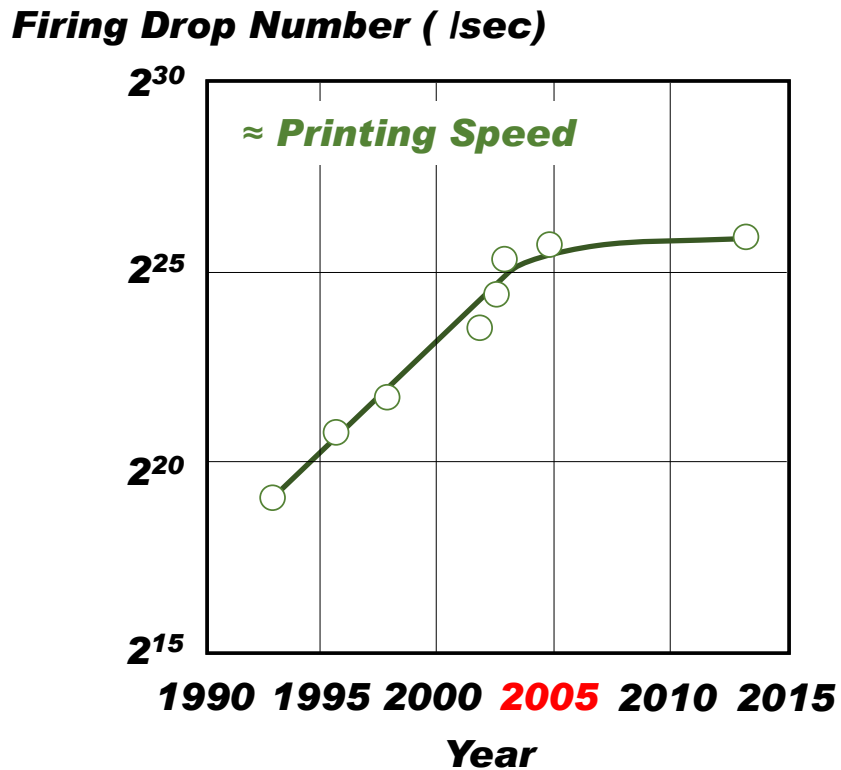
Speed Factor (Print Speed)

≈ Print Speed

$$\text{Speed Factor} = \frac{\text{Frequency} * \text{Nozzle Number}}{\text{Multi-Path} * \text{Resolution} * \text{Print Direction}} - \text{Maintenance} - \text{Others}$$



Until 2005

Tilt : $2^{0.5}$ = Moore's Low

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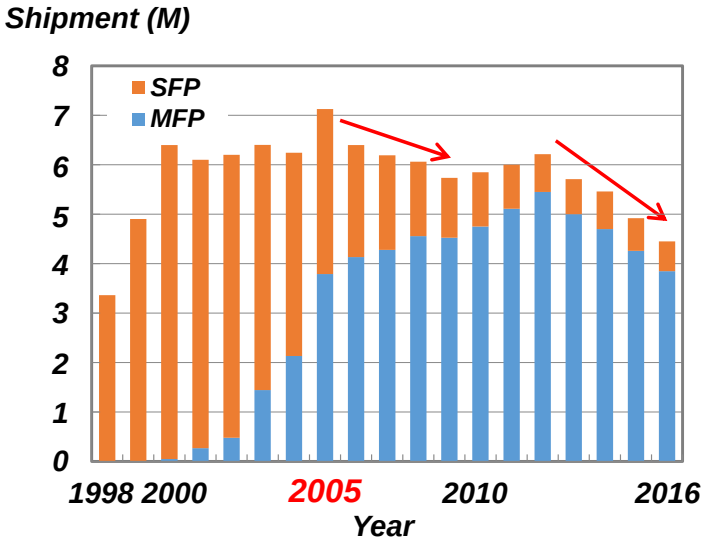
End of CFP in Consumer Products

- **Increase of key components performance has almost saturated, and progress of printer performances (image quality, print speed) have ticked over since 2005.**
- **If additional technology developments focusing on consumer market stop, no consumer will feel inconvenient.**
- **I don't mean that all ink jet technology developments should be stopped.**



Volume of Ink Jet printer Shipment in Japan

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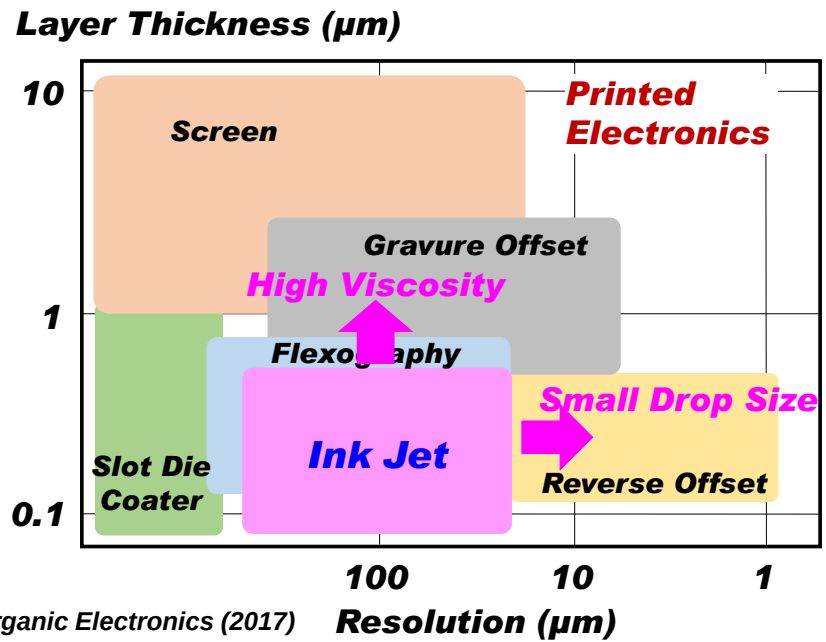
New Progress Type

- Technologies progress of ink jet stop? NO!
- Concentrating Functions Progress (CFP) is still required in other market with different performance axis (required performance) [DF] NOT consumer's.

CFP is only approaches in ink jet ?



- New type of technology progress has been necessary for new printer market with new hard issues.
- One of new markets is commercial printing, and new progress type is Sharing Functions Progress (SFP).

S. Tokito, The 4th Workshop on Flexible Organic Electronics (2017)

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Plane View of Ink Jet Market

Digital Fabrication

Image Quality

Concentrating Functions Progress

Concentrating Functions Progress

Home

Photo Finishing

Pagewide Printhead

Commercial Printing

Office

Sharing Functions Progress

High

Low / Mid.

Transactional

Light Production

Serial Printhead

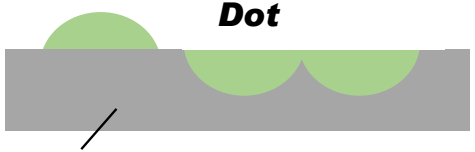
: Technical Difficulties to Overcome Boundary

Print Speed

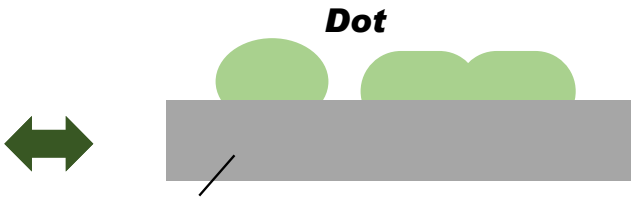
Serious Issues in Commercial Printing Market

Ink Jet Media

Existing Market
(Consumer, Office, Photo)



Commercial Printing Market



Offset Coated Paper

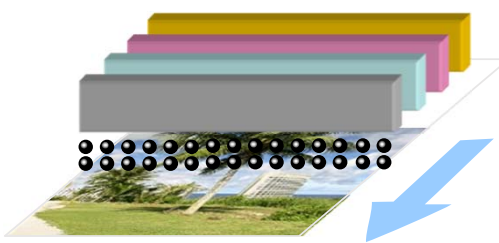
Image Forming
On Non-Permeable Media

Challenge

New Type of Technology Progress
Not Saddle Printhead or Ink

Sharing Functions Progress

No Multi-Pass



Line Printer : One Pass Process

Compatibility of High Speed & High Image Quality

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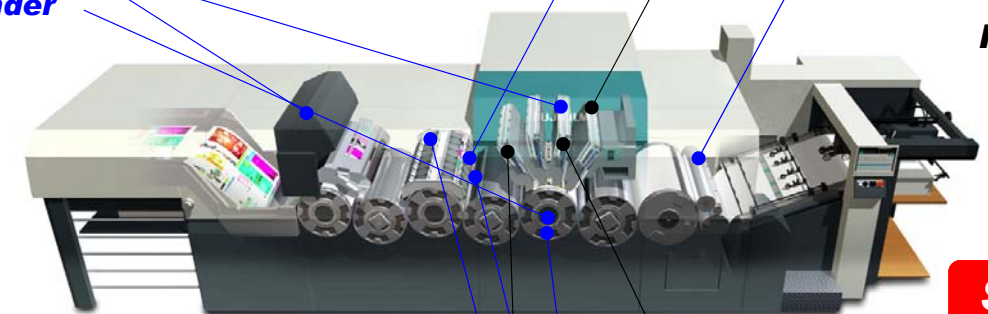
Sharing Functions Progress (SFP)

One Pass Image Quality for Commercial Printing

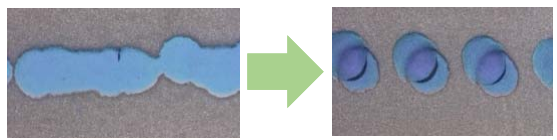
- Defect Detection
- Defect Compensation
- Impression Cylinder

Image Forming On Non-Permeable Media

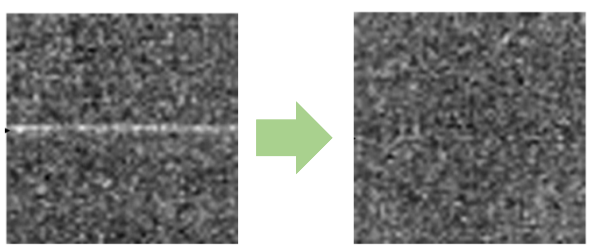
- Under-Coating
- Drying System
- Latex Ink



- Drying System
- Anti-Curl Agent
- Impression Cylinder
- Air Conditioner
- Pagewide Printhead



No Under-Coating Under-Coating



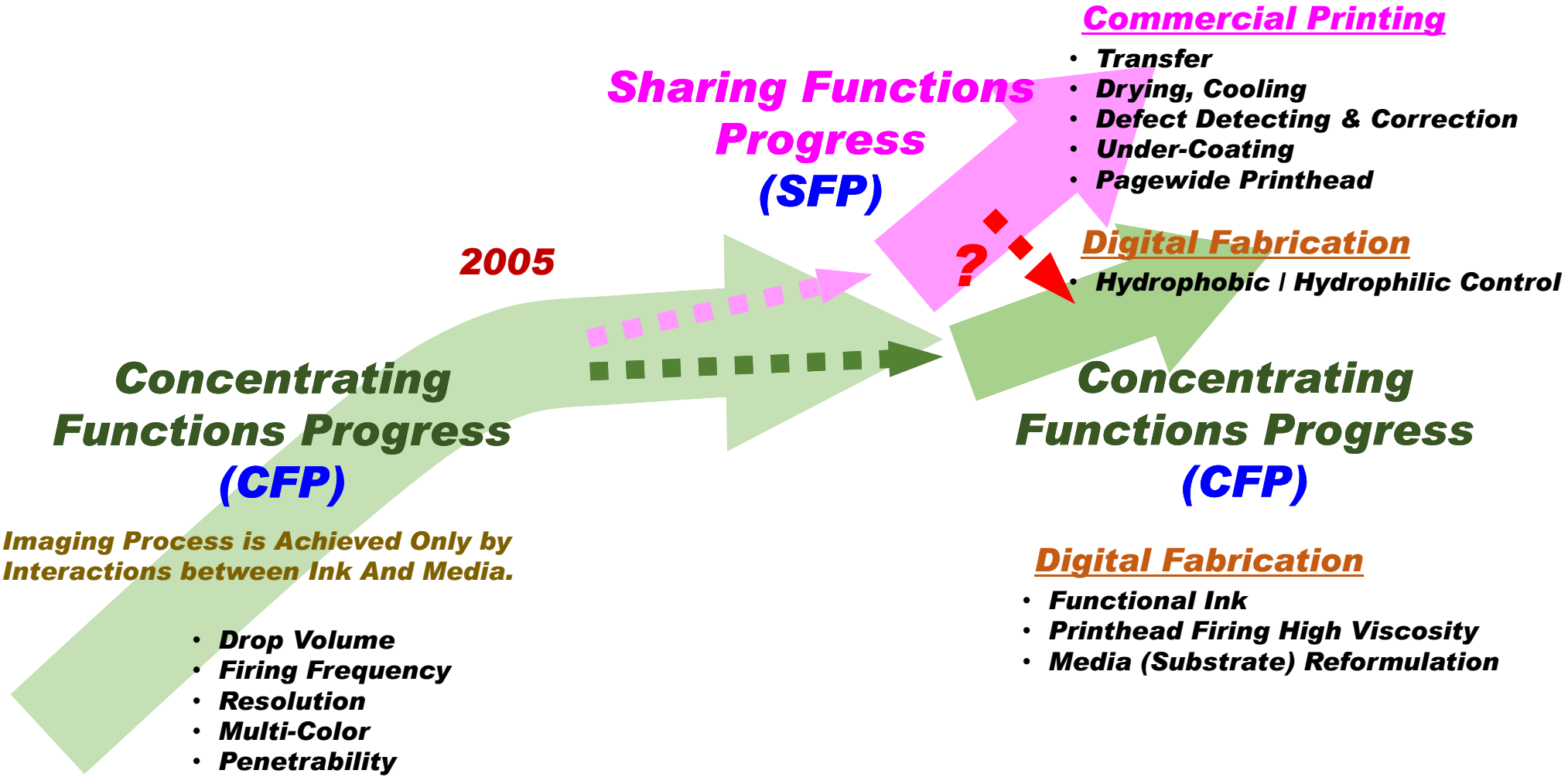
Before Compensation After Compensation

Sharing Functions Progress

Many ink jet Merits (small size, low cost, low energy Consumption) are lost.

High Speed Printing with Cut Paper

Direction of Technology Progress



Innovation Portfolio by Henderson & Clark

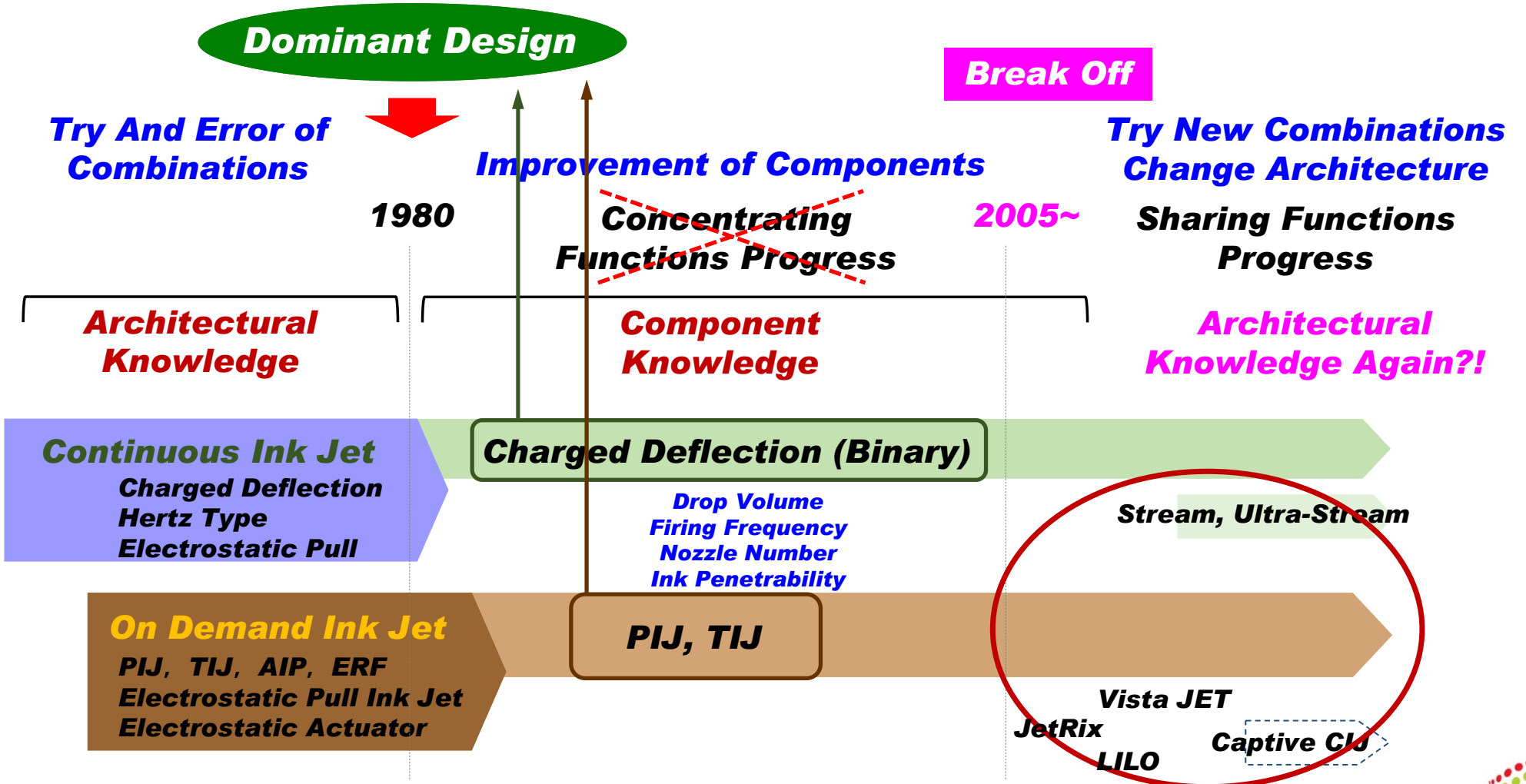
Architecture	Reinforced	Overturned
Changed	≈SFP **Architectural Innovation** Architectural Knowledge	**Radical Innovation**
Unchanged	CFP **Incremental Innovation** Component Knowledge	**Modular Innovation**

Architecture
Linkage between Core Concepts and Components

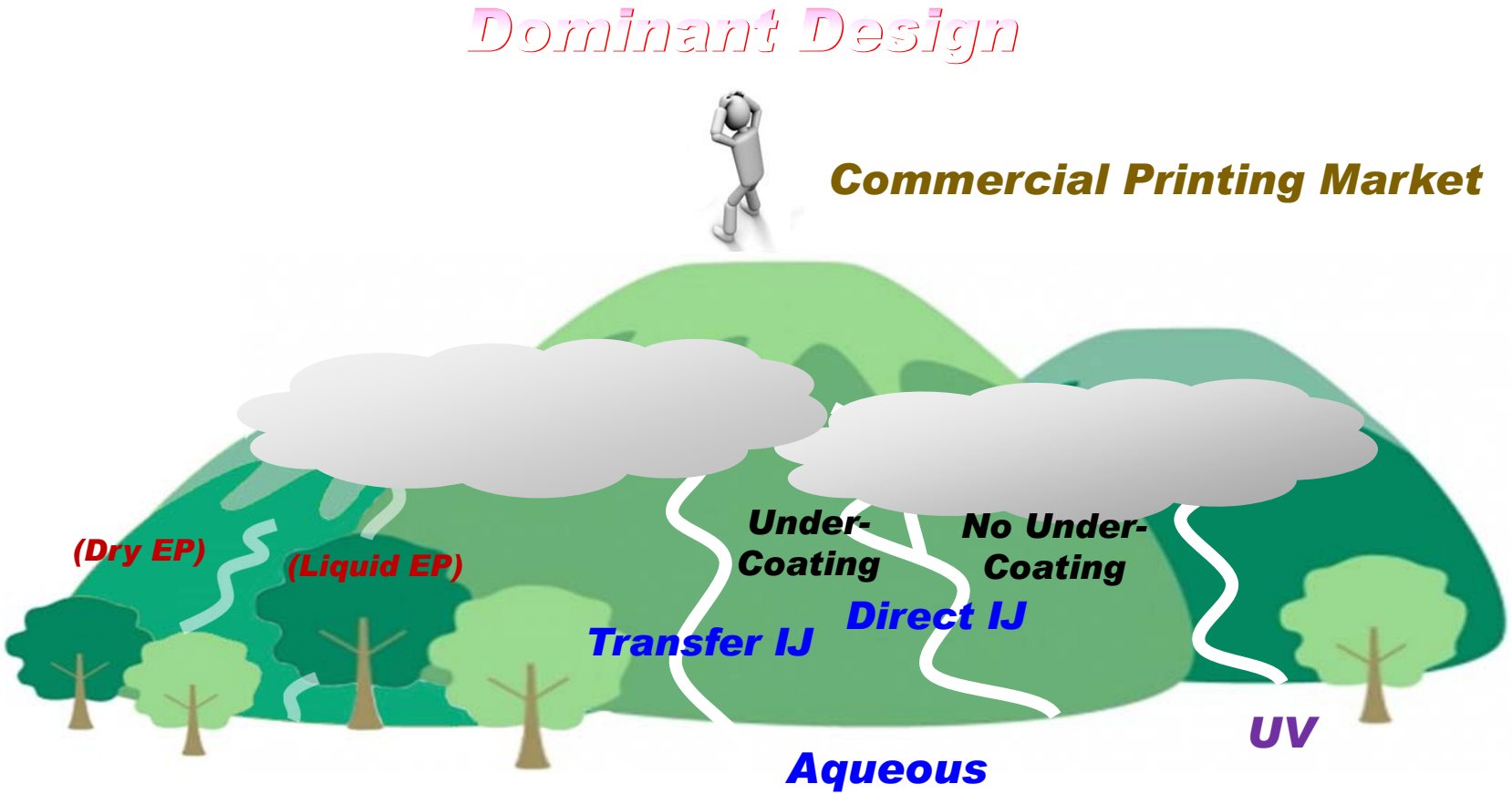
Core Component
(Core Concept)


R. Henderson & K. Clark, Architectural Innovation: The Reconfiguration Existing Product Technologies and the Failure of Established Firm (1990)

Technology Progress of Ink Jet

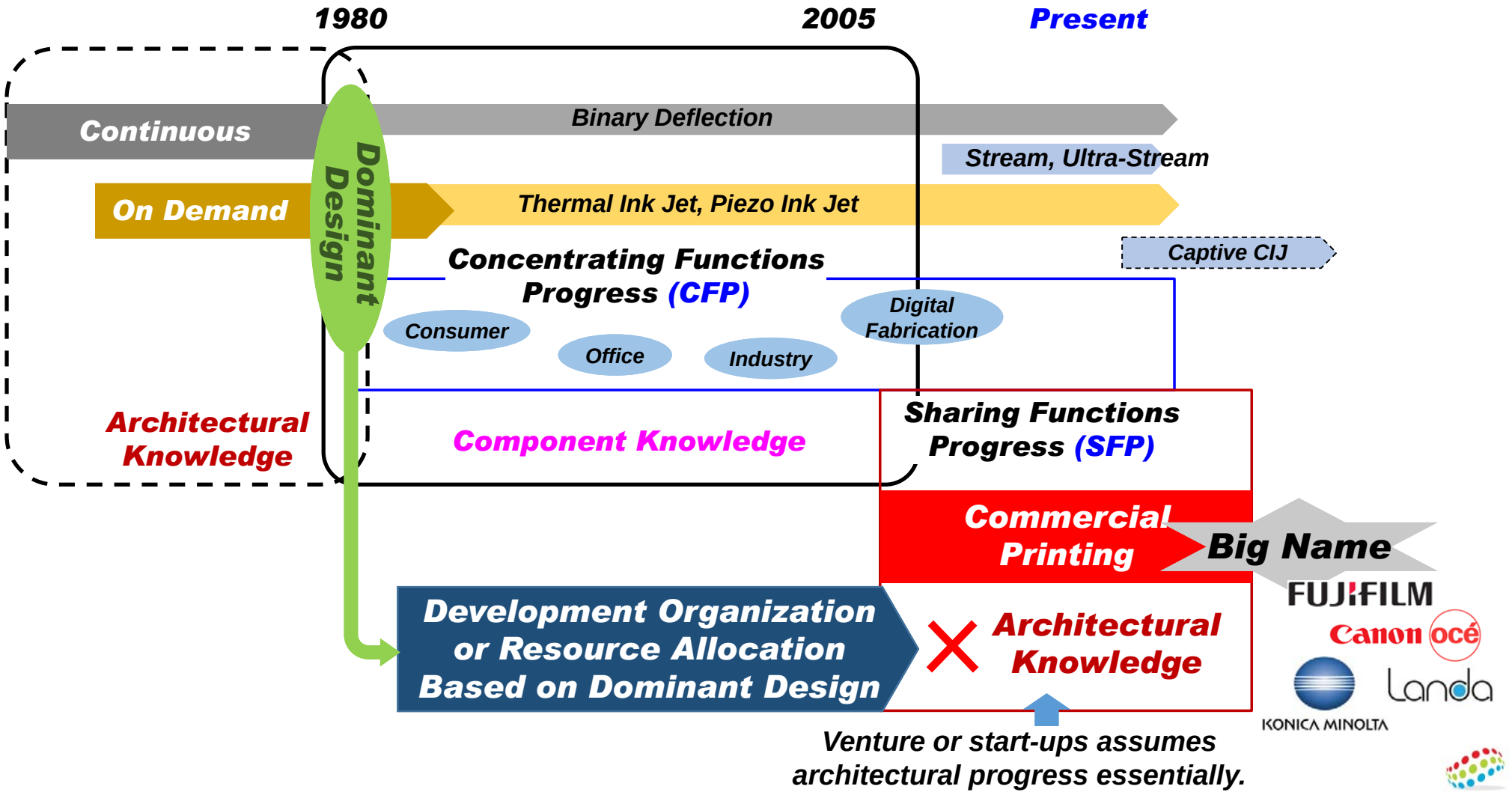


Approaches & Dominant Design



✓ ***Various ink jet approaches to commercial printing exist, but the dominant design has NOT been established yet.***

Contradiction of Progress in Commercial Printing Market



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Contradiction of Progress in Commercial Printing Market

- ***Architectural Innovation should be brought by venture companies or start-ups essentially.***
- ***On the other hand, Big companies have stored ink jet technologies and know-how required for commercial printing market.***
- ***Here, we have contradiction of progress.***
- ***No one can stop digitalization of commercial printing, what this contradiction brings?***

Contrivances to Activate Ink Jet Technologies Progress

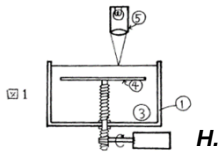
For both SFP (Architectural Innovation) and CFP (Incremental Innovation),

- ***Full-Blown ink jet technologies owned by ink jet companies should be transfer or licensed to new challengers. (Don't enclose for the already stop-glowing market.)***
- ***Engineers and Researchers network (Community) will help to share common information and create new applications and make innovations.***

Ink Jet Inkcube Incubation

Ink Jet Technical Networking (Community) in Japan

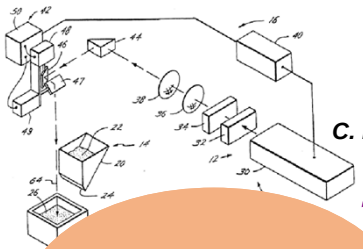
Architectural progress in Additive Manufacturing



H. Kodama

1980

Vat Photo-polymerization

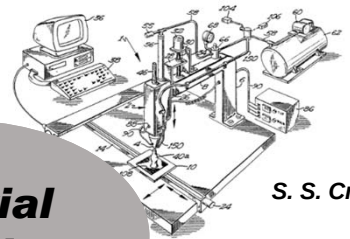


C. R. Deckard

1986

Powder Bed Fusion

1989



S. S. Crump

Material Extrusion

Additive Manufacturing Is Categorized into 7 Methods.

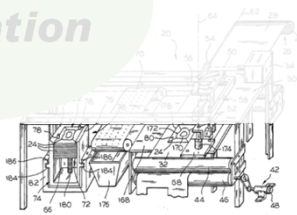
These 7 Methods were Invented in 1980's or 1990's.

About 30 years pasts, then…

1987

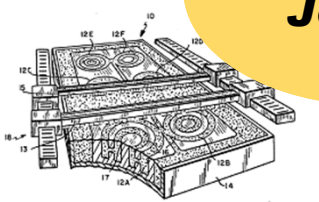
M. Feygin

Sheet Lamination



1989

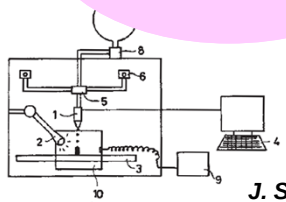
Binder Jetting



E. M. Sachs

1989

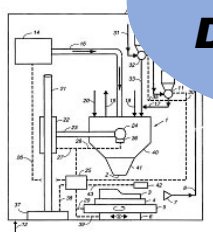
Material Jetting



J. Sakai

1995

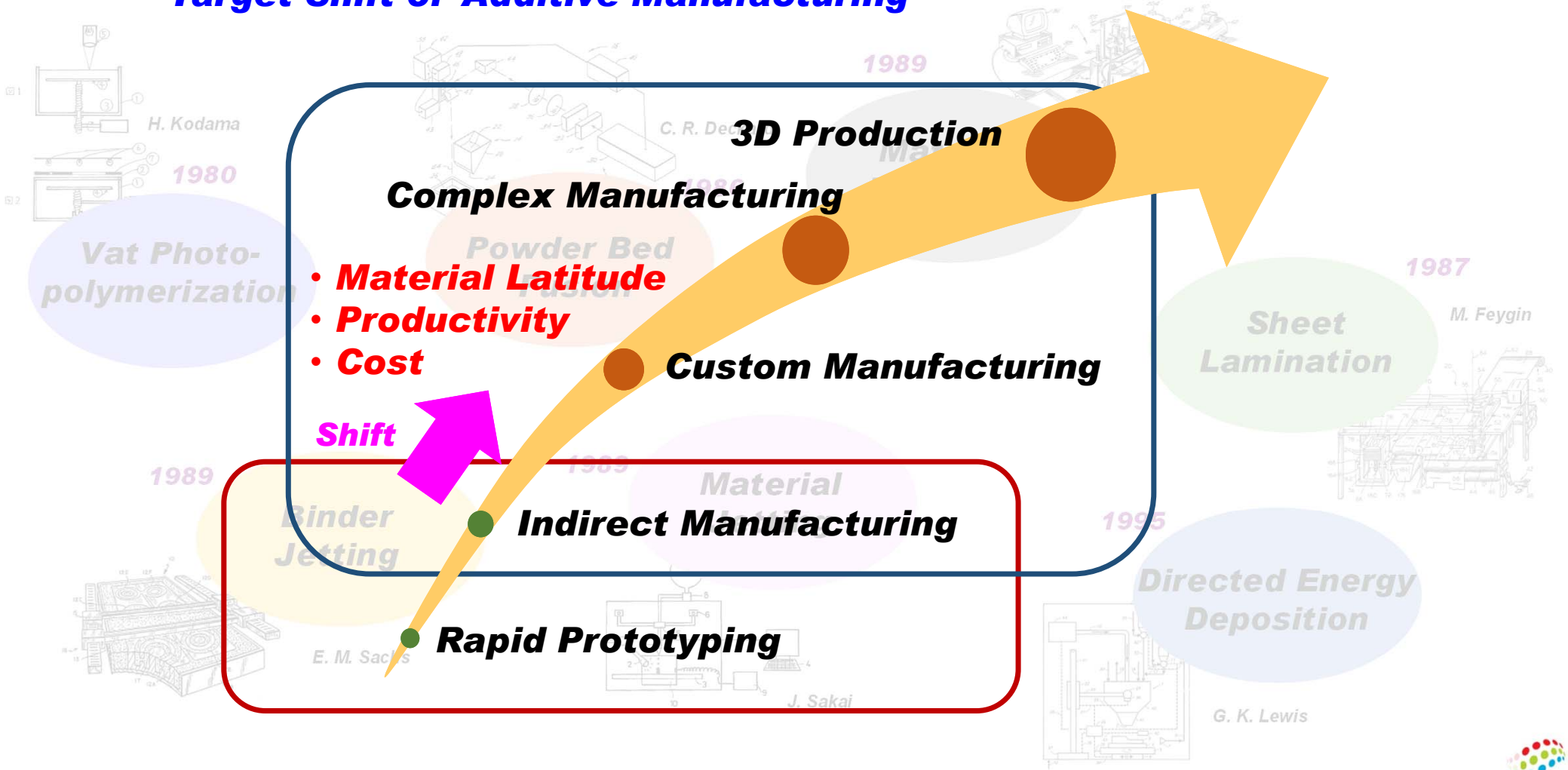
Directed Energy Deposition



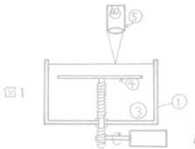
G. K. Lewis

Architectural progress in Additive Manufacturing

- Target Shift of Additive Manufacturing



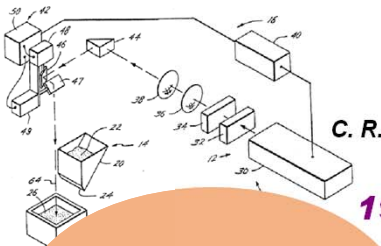
Architectural progress in Additive Manufacturing



H. Kodama

1980

Vat Photo-polymerization

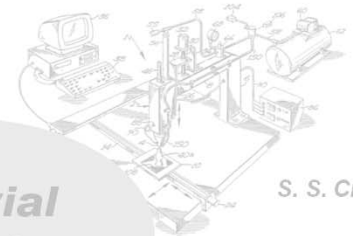


C. R. Deckard

1986

Powder Bed Fusion

1989



S. S. Crump

Material Extrusion

HP

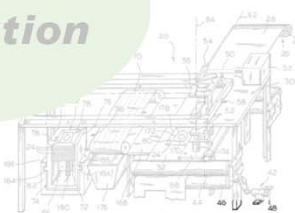
Multi Jet Fusion

2017

1987

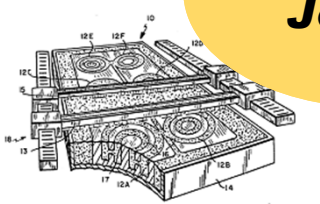
M. Feygin

Sheet Lamination



1989

Binder Jetting



E. M. Sachs

1989

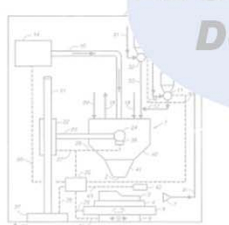
Xaar & Loughborough University

High Speed Sintering

J. Sakai

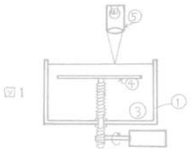
1995

Directed Energy Deposition



G. K. Lewis

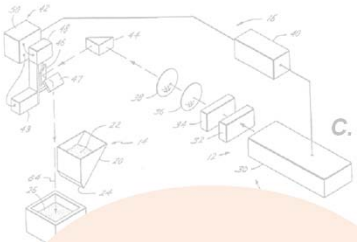
Architectural progress in Additive Manufacturing



H. Kodama

1980

Vat Photo-polymerization



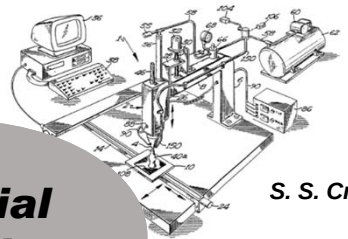
C. R. Deckard

1986

Powder Bed Fusion

1989

Material Extrusion

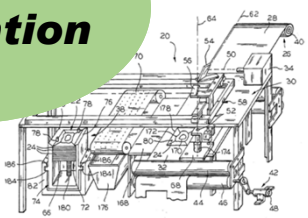


S. S. Crump

1987

Sheet Lamination

M. Feygin



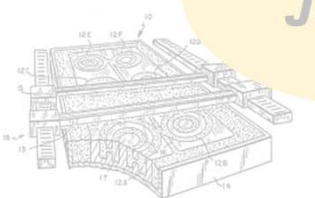
2017

XYZ Printing

da Vinci Color 3D printer

1989

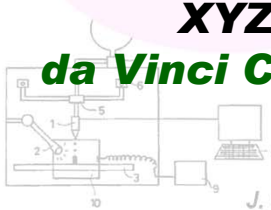
Binder Jetting



E. M. Sachs

1989

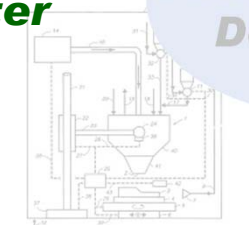
Mat... Jetting



J. Sakai

1995

Directed Energy Deposition



G. K. Lewis

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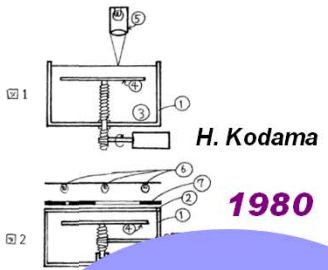
Architectural progress in Additive Manufacturing



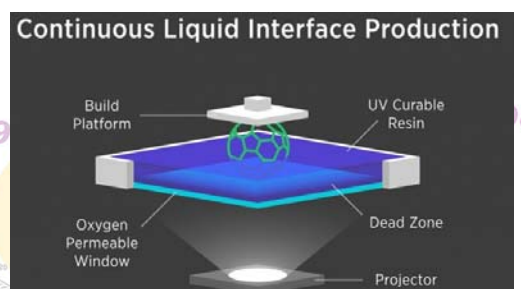
1980

Vat Photo-polymerization

2016

Carbon

CLIP



In R&D Phase

- **Many New processes (new architectures) not categorized in 7 existing methods have been researched and proposed.**

Powder Bed Fusion

Sheet Lamination

M. Feygin

Material Jetting

J. Sakai

1995

Directed Energy Deposition

G. K. Lewis

Listen this afternoon's Keynote please.

Inkcube

Conclusion & Suggestion

- ***2005* was one of important turning years for ink jet technology progress.**
- **Two type of ink jet technology progress exist.**
  - **Concentrating Functions Progress (*CFP*)**
  - **Sharing Functions Progress (*SFP*)**
- ***CFP* generates Incremental Innovation, *SFP* brings Architectural Innovation.**
- ***CFP* is still required for digital fabrication, *SFP* is necessary for commercial printing.**
- **In commercial printing market, a contradiction of progress has occurred, and *dominant design* has NOT been established yet.**
- **Full-blown ink jet technologies owned by ink jet companies should be transferred or licensed to new challengers to activate both *CFP* and *SFP*.**


Thank You for Your Kind Attention !