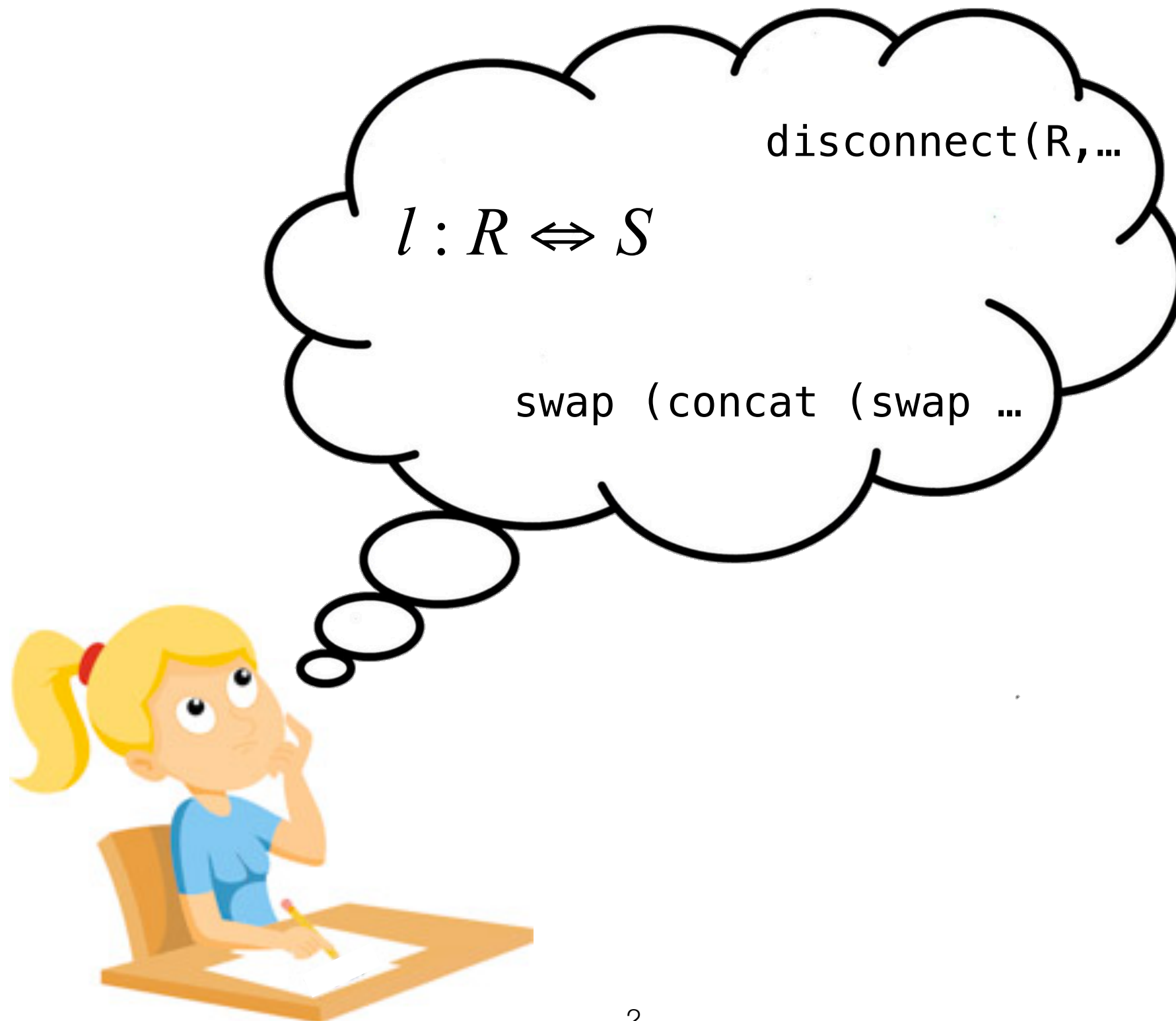


# Expanding the Power of Lens Synthesis

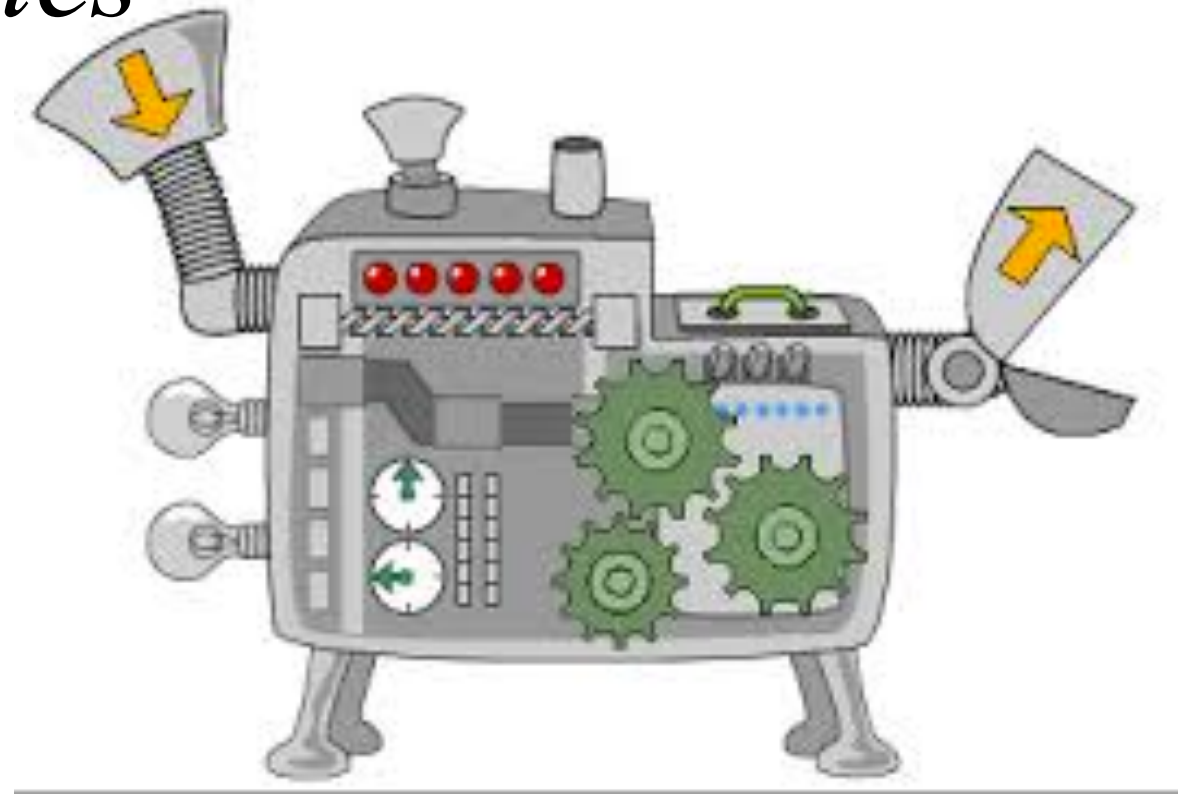
Anders Miltner, Solomon Maina, Kathleen Fisher,  
Benjamin C. Pierce, David Walker, Steve Zdancewic

# Learning DSLs is Hard



# Synthesis as a Solution

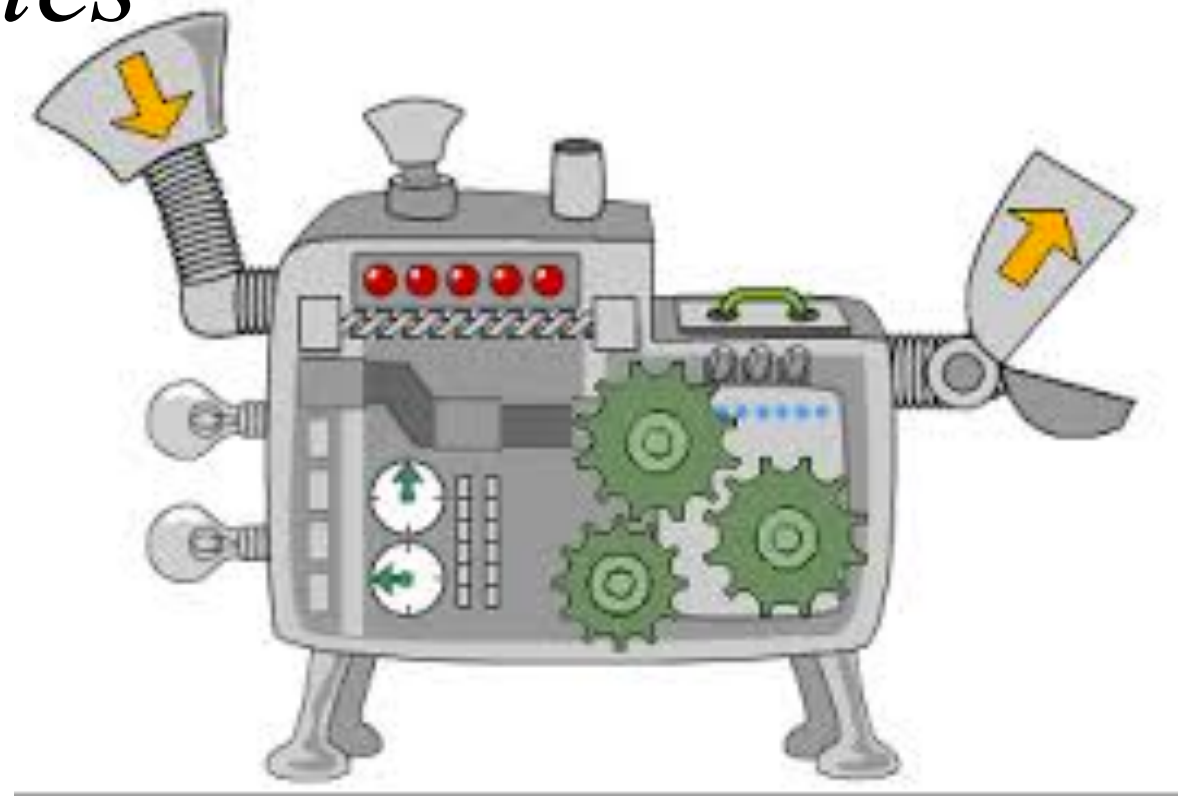
$R, S$   
*examples*



$$l : R \Leftrightarrow S$$

# Synthesis as a Solution

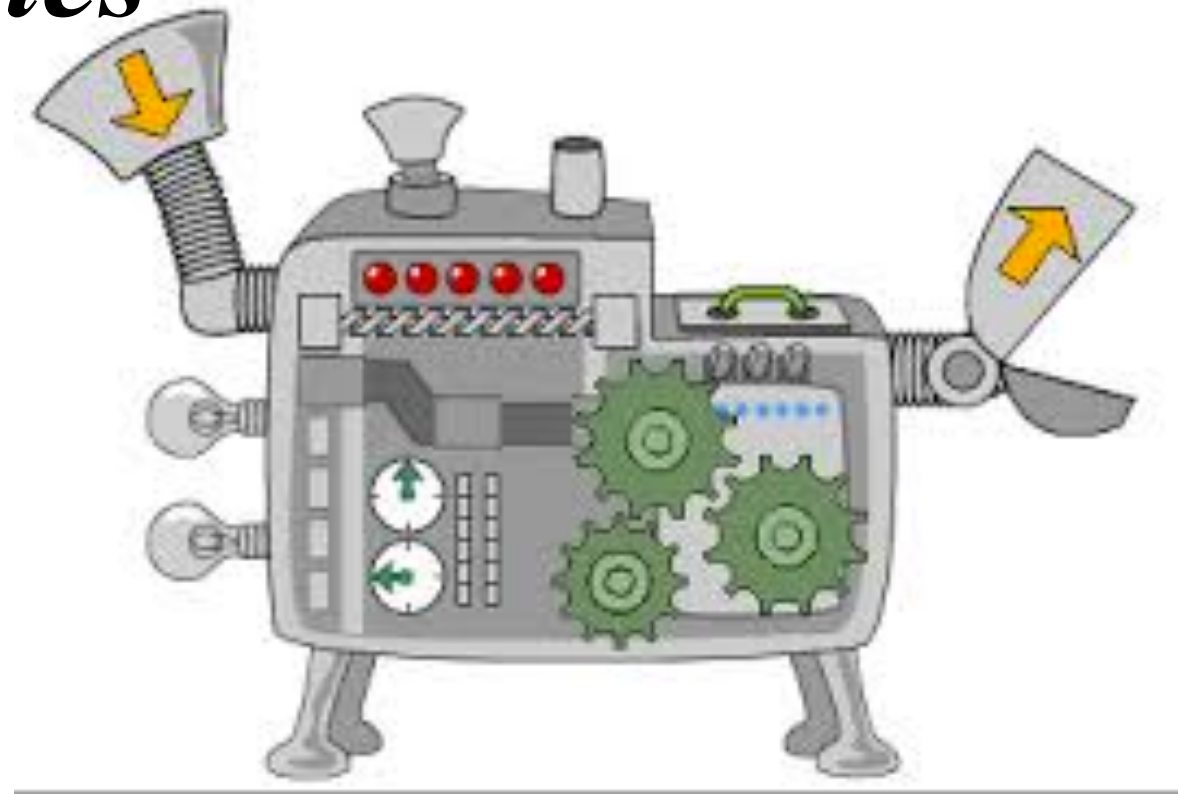
$R, S$   
*examples*



$$l : R \Leftrightarrow S$$

# Synthesis as a Solution

$R, S$   
*examples*



$$l : R \Leftrightarrow S$$

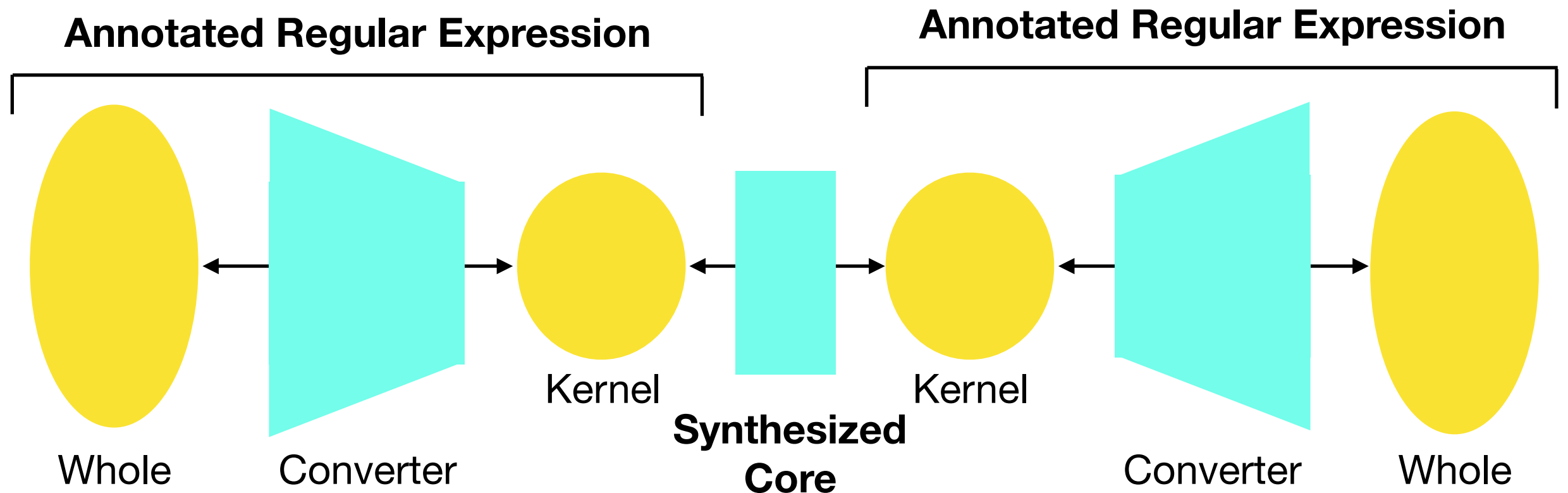
# Synthesizing Bidirectional Programs

- Optician [Miltner et al. 2018, Maina, et al. 2018, Miltner et al. 2019] synthesizes lenses from regular expression pairs
- Integrated into Boomerang [Bohannon et al. 2008]

*Optician*



# A Framework for Lens Synthesis

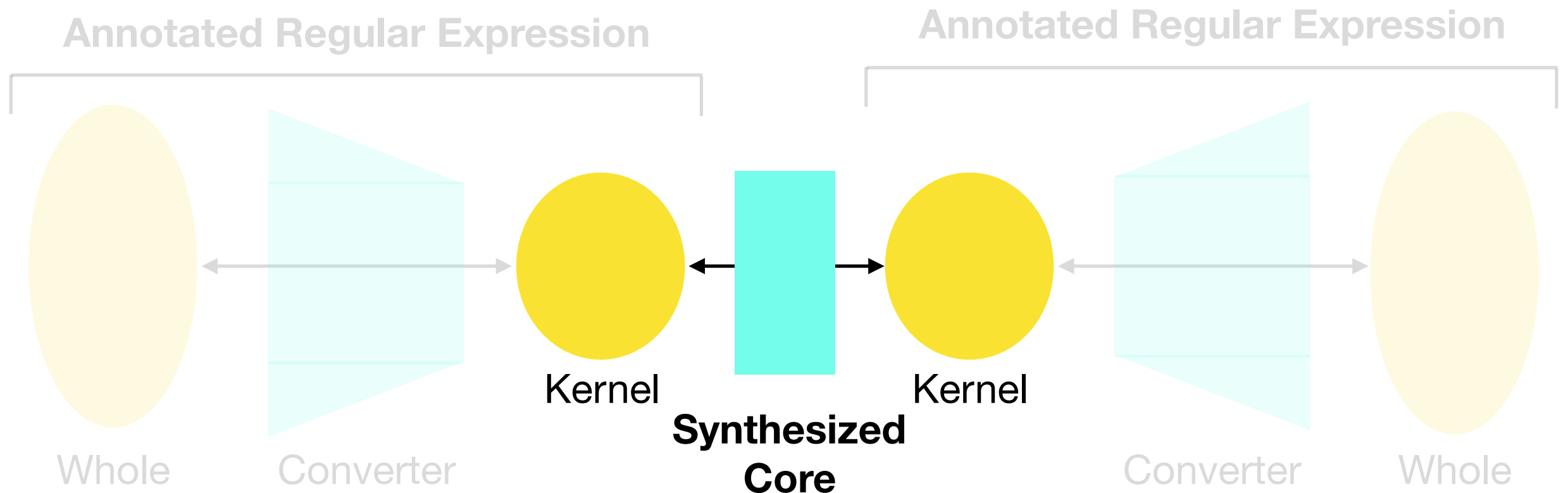


# We can synthesize...

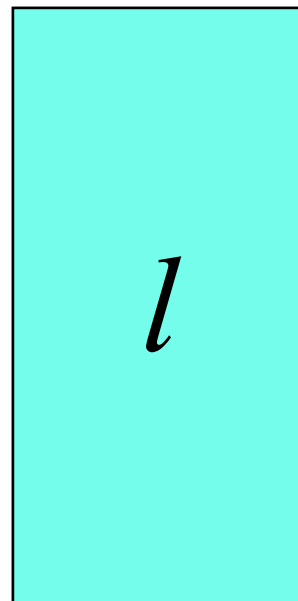
- Bijective Lenses
- Quotient Lenses
- Asymmetric Lenses
- Symmetric Lenses



# Bijection Lens Synthesis



# Bijjective Lenses

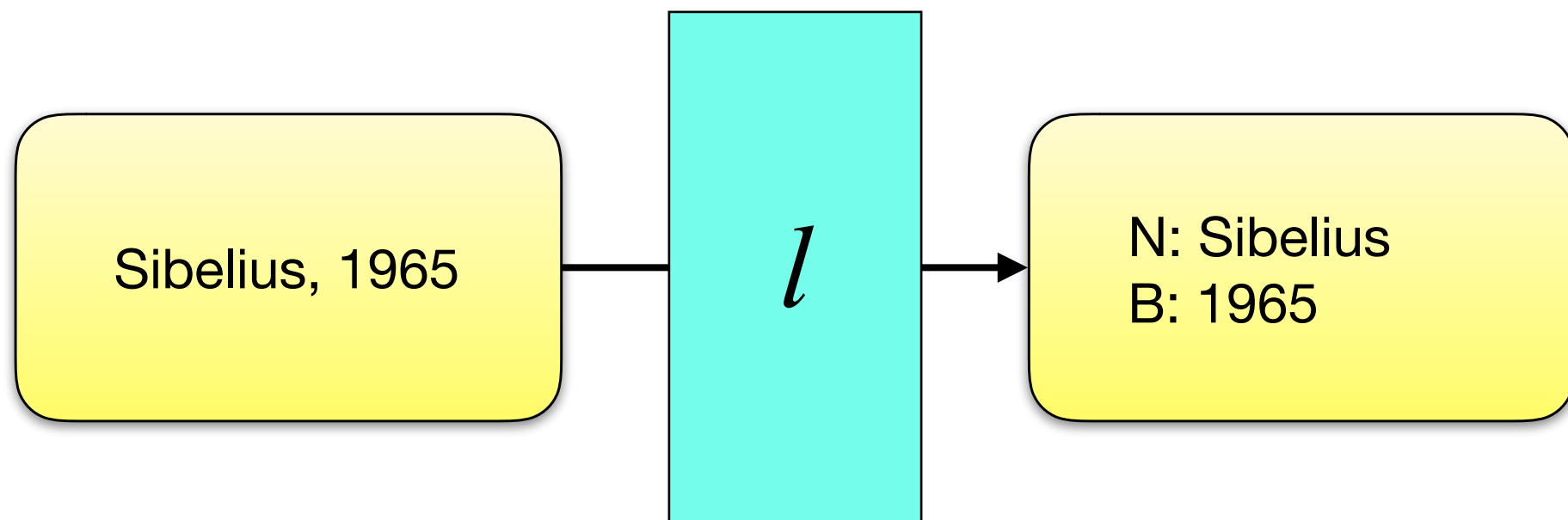


# Bijjective Lenses

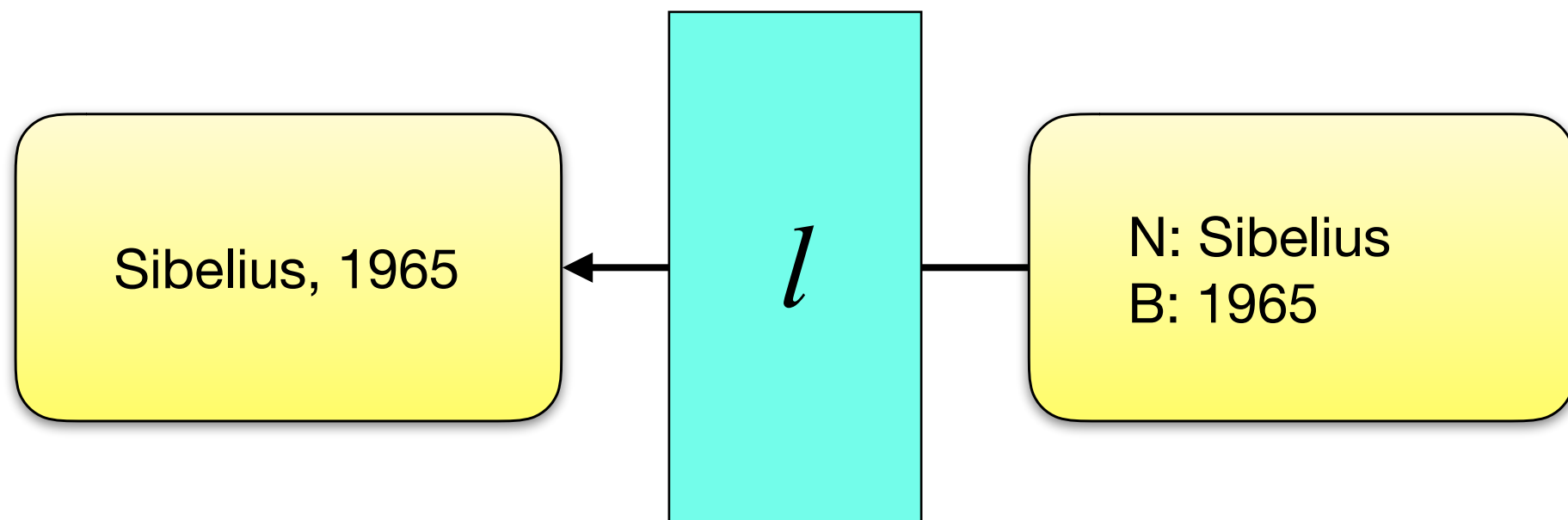
Sibelius, 1965

*l*

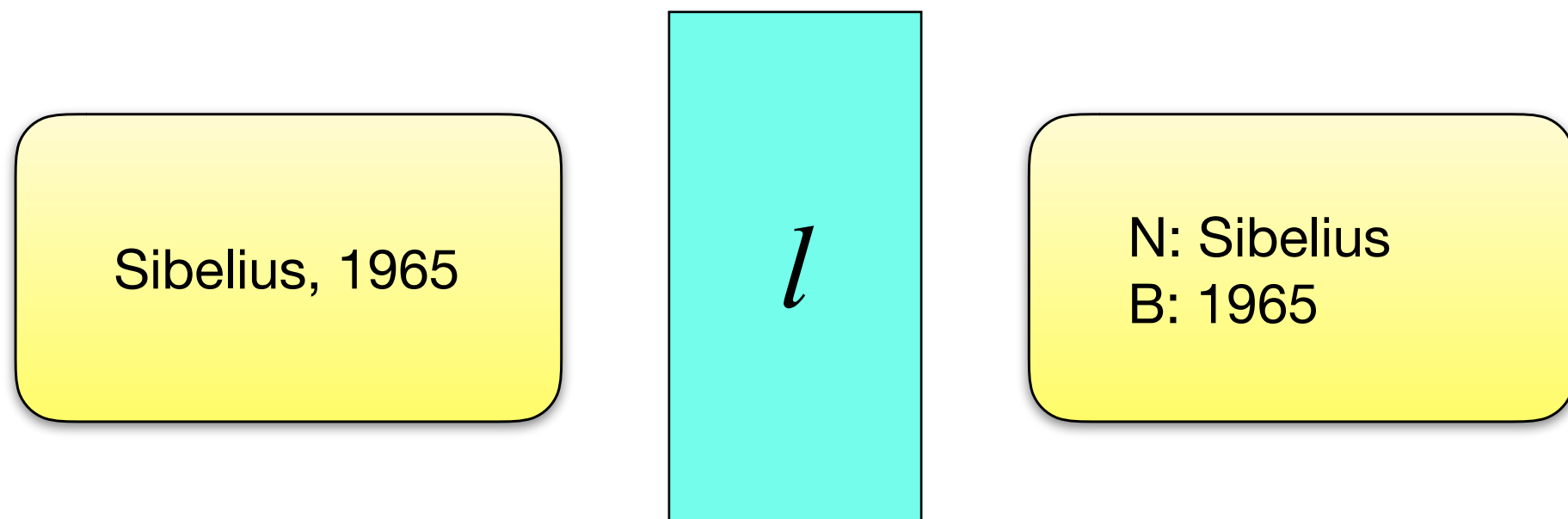
# Bijjective Lenses



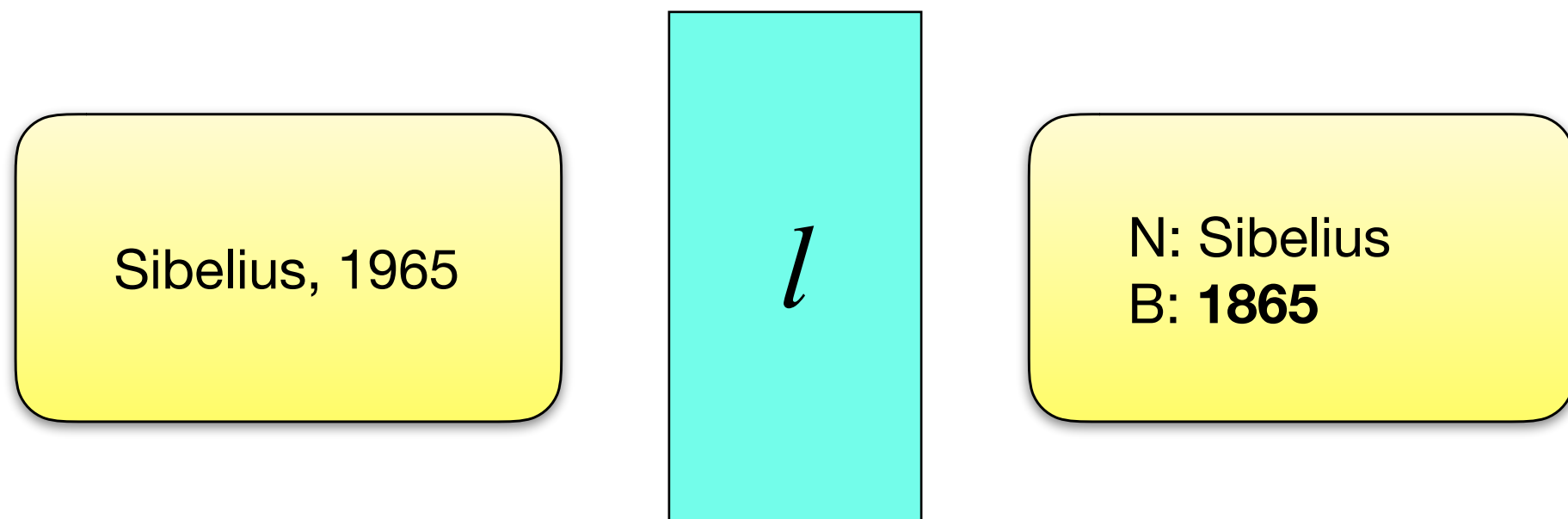
# Bijjective Lenses



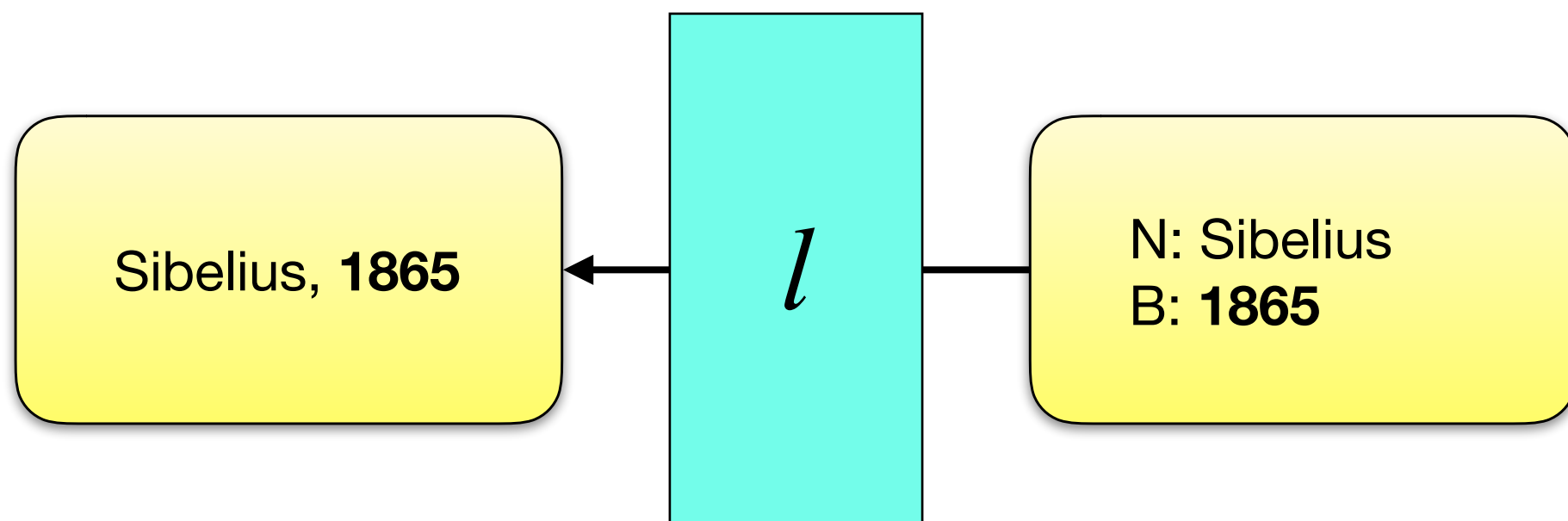
# Bijjective Lenses



# Bijjective Lenses



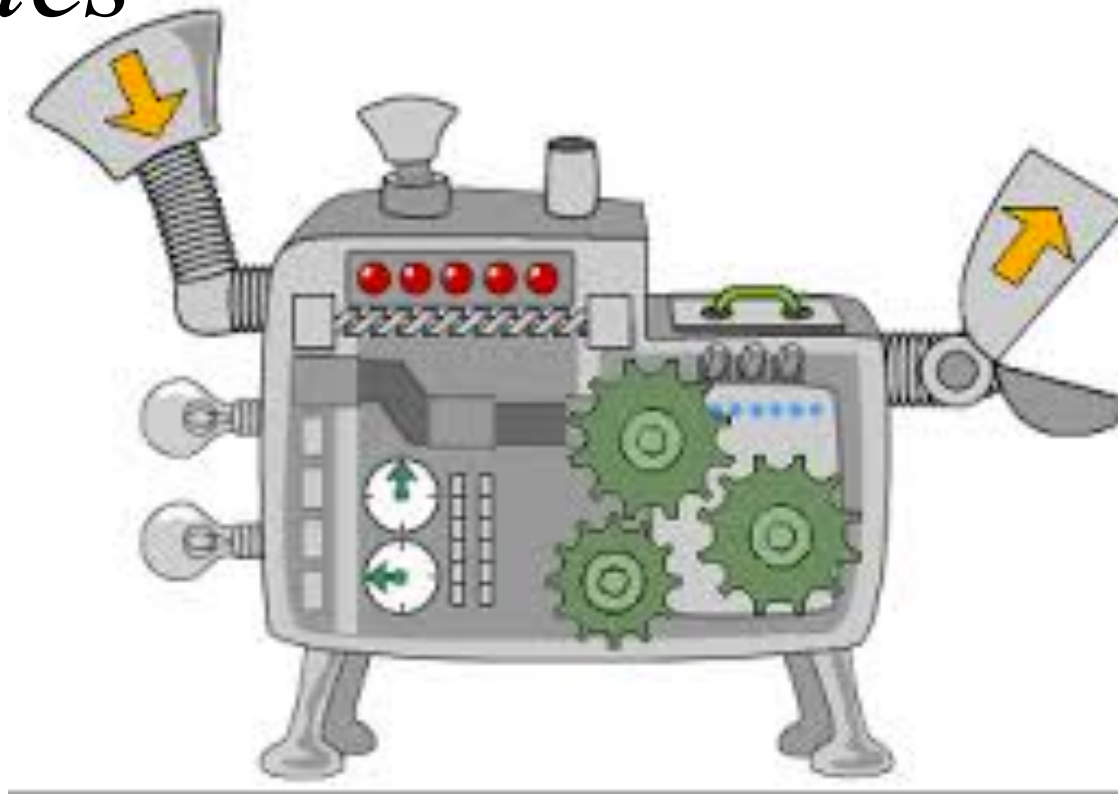
# Bijjective Lenses





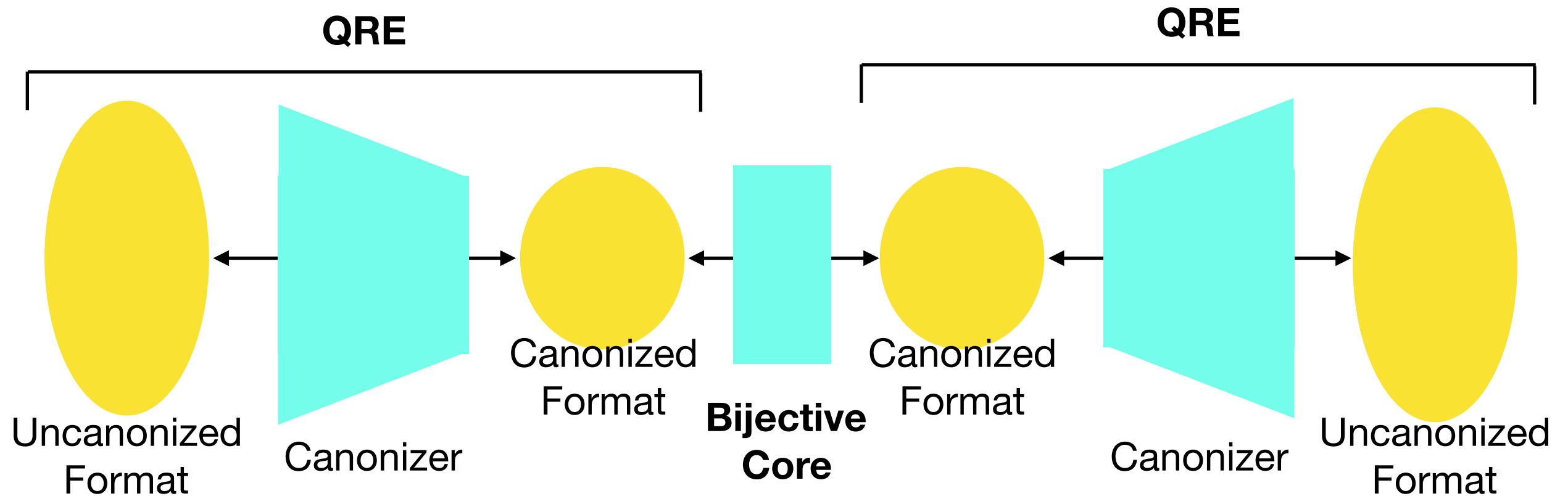
# Bijjective Synthesis

$R, S$   
*examples*

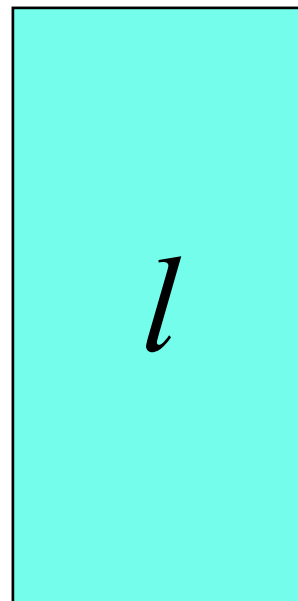


$$l : R \Leftrightarrow S$$

# Quotient Lens Synthesis



# Quotient Lenses

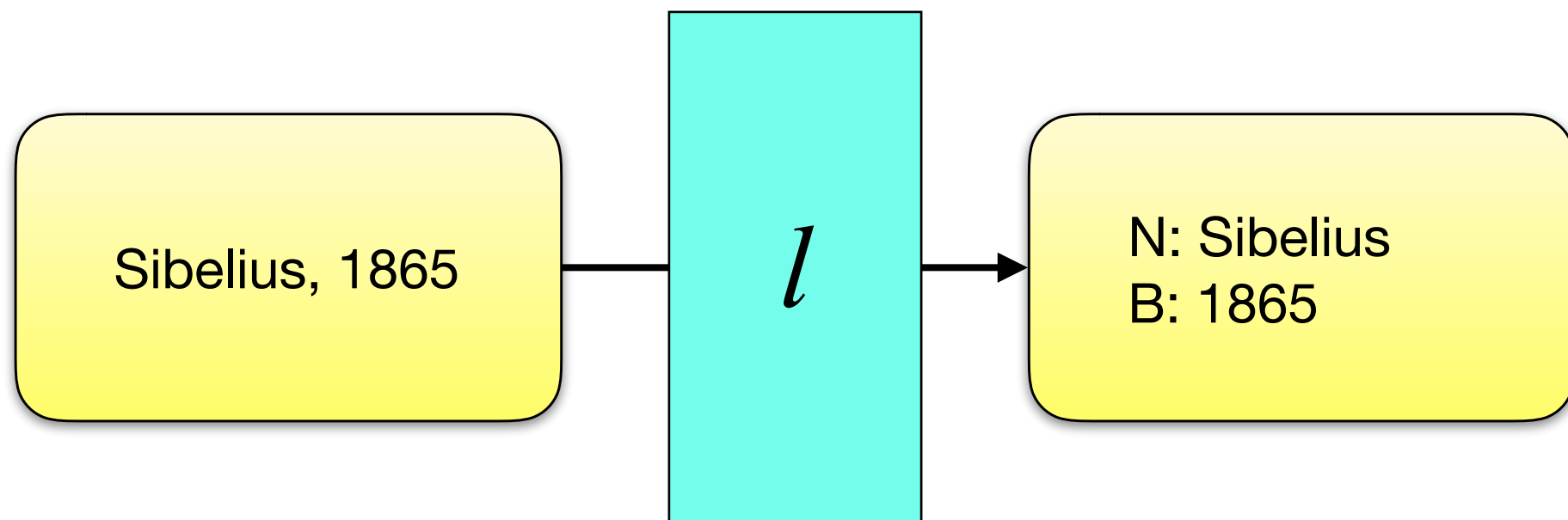


# Quotient Lenses

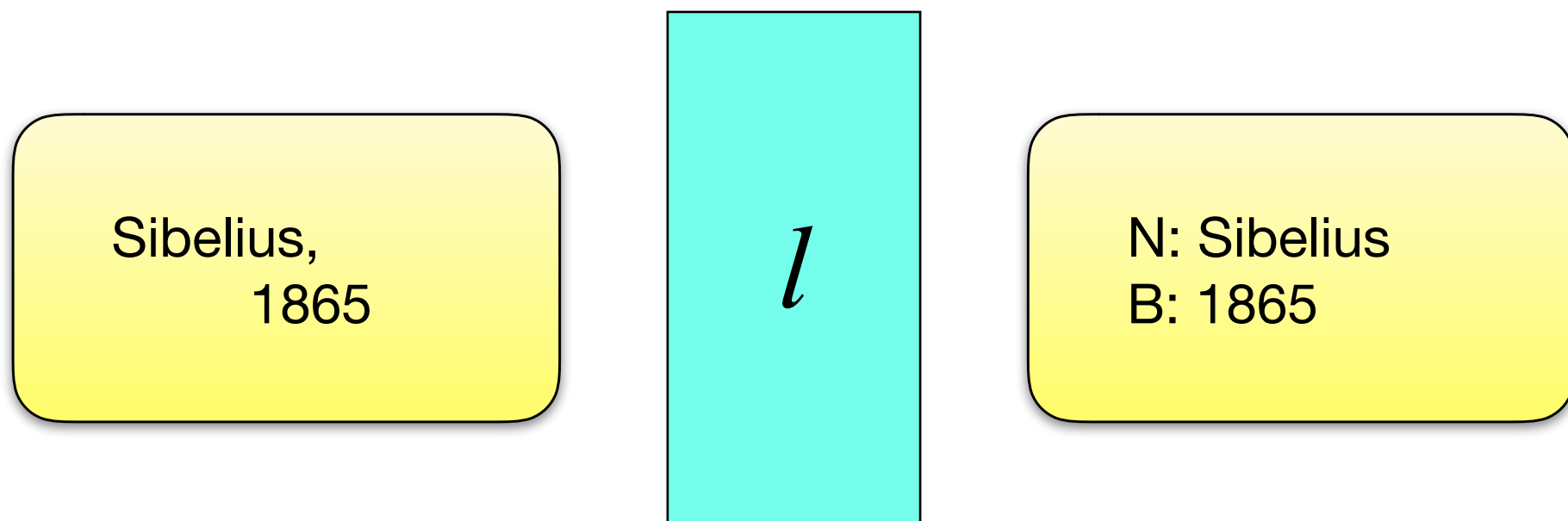
Sibelius, 1865

$l$

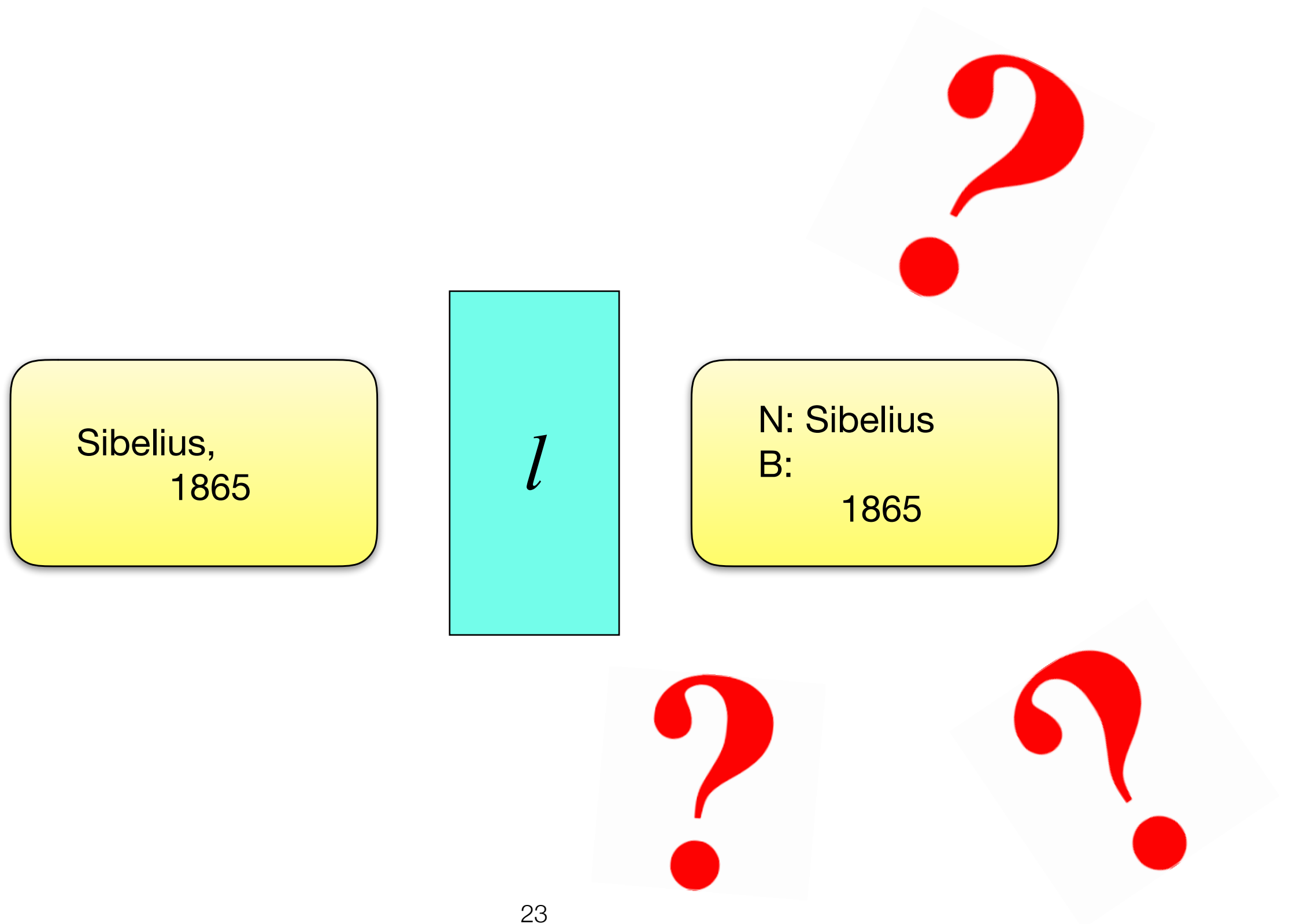
# Quotient Lenses



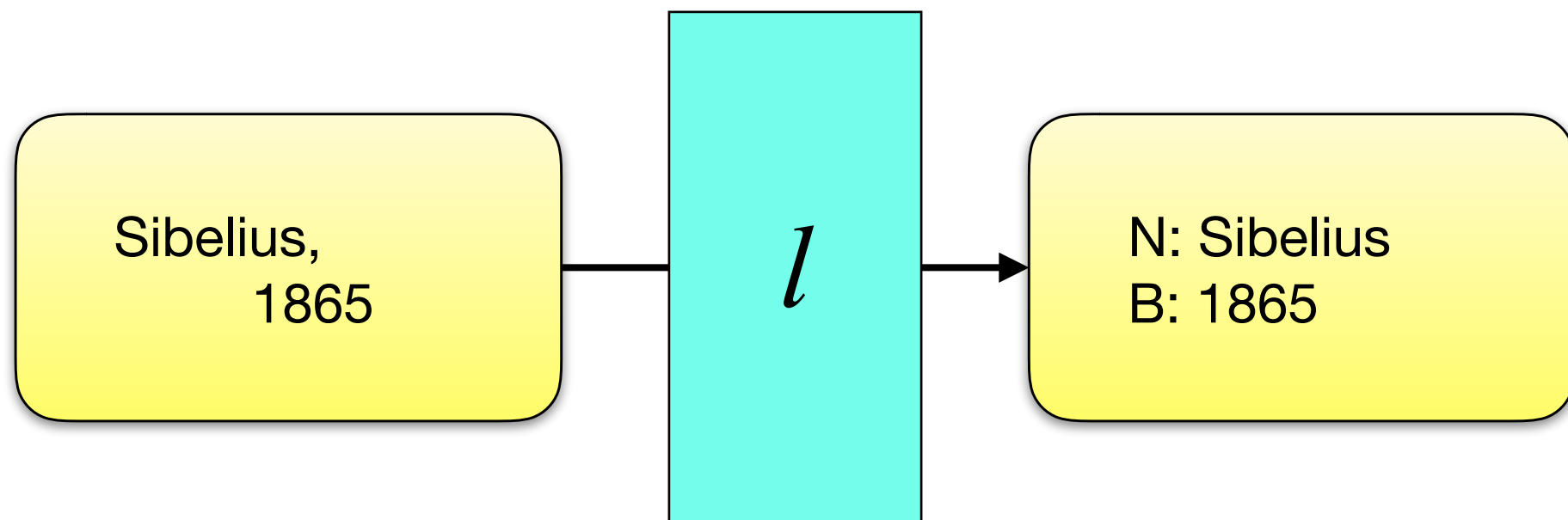
# Quotient Lenses



# Quotient Lenses



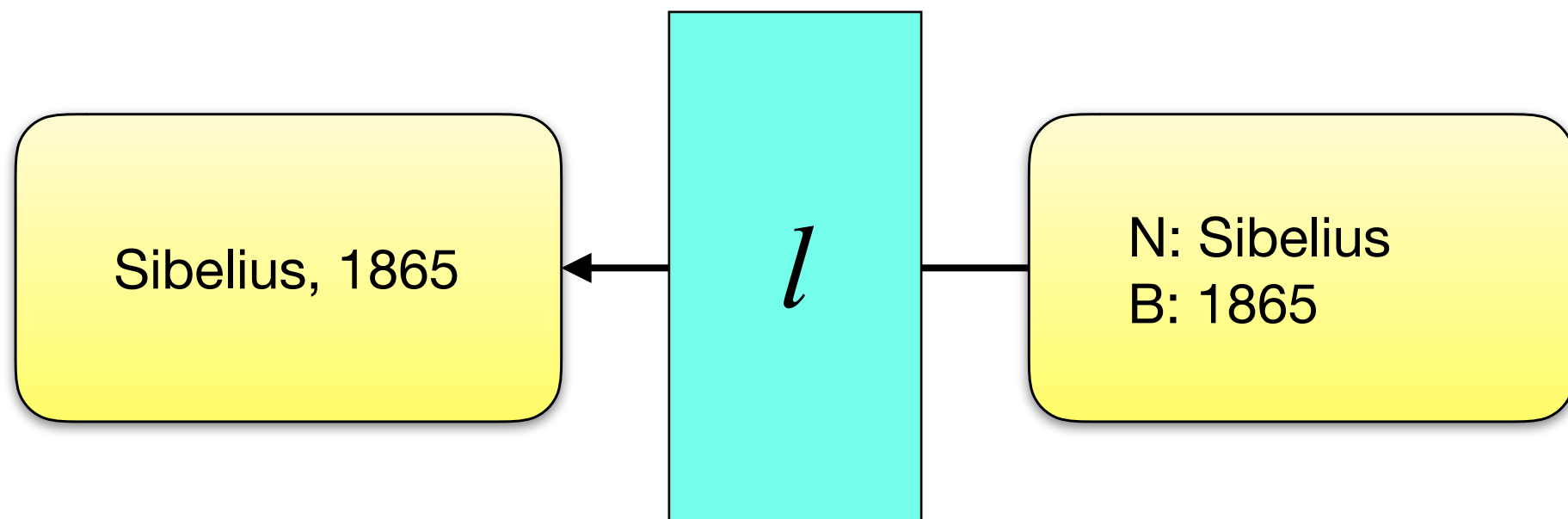
# Quotient Lenses



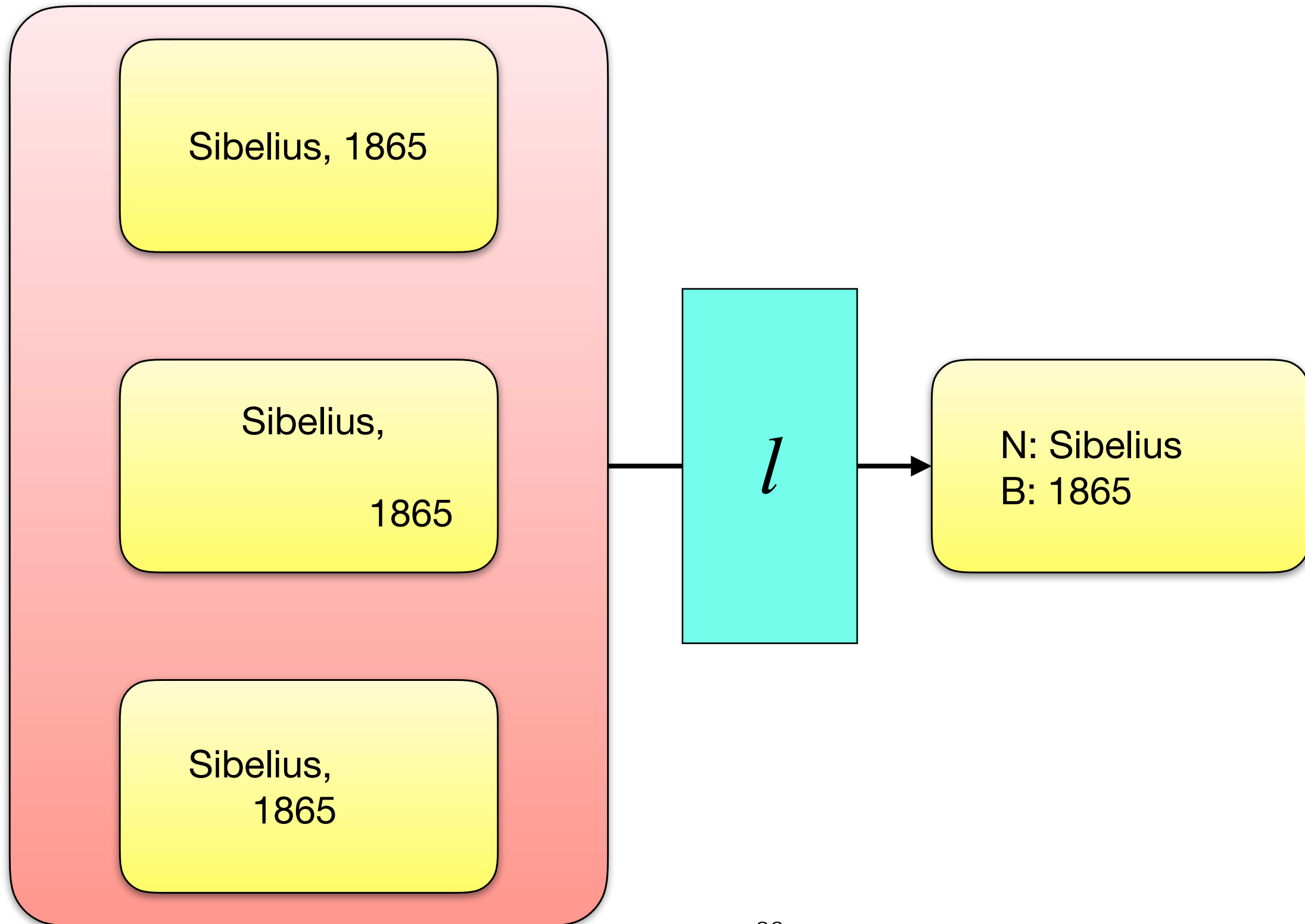


# Quotient Lenses

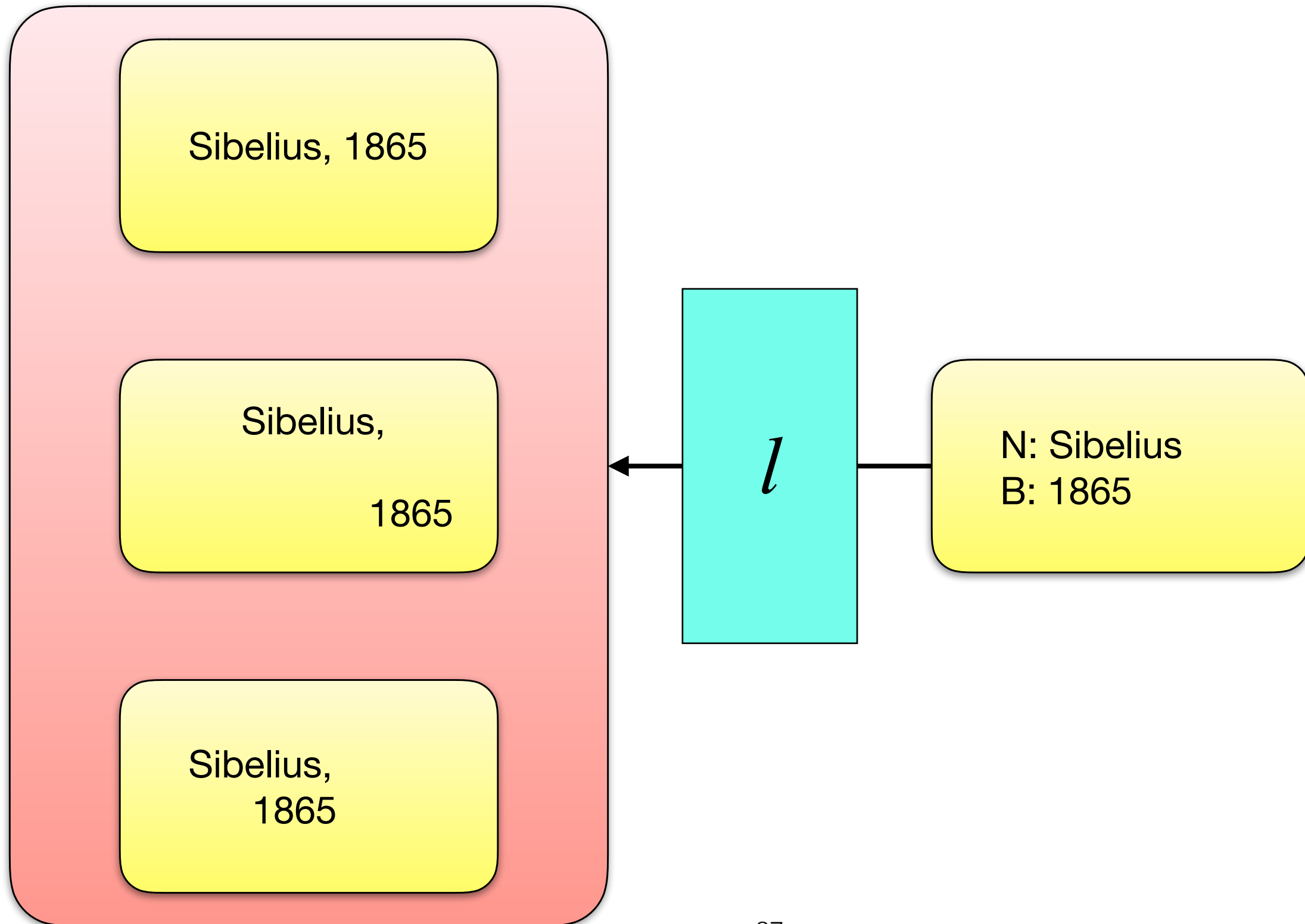
**Permissive in input**  
**Restrictive in output**



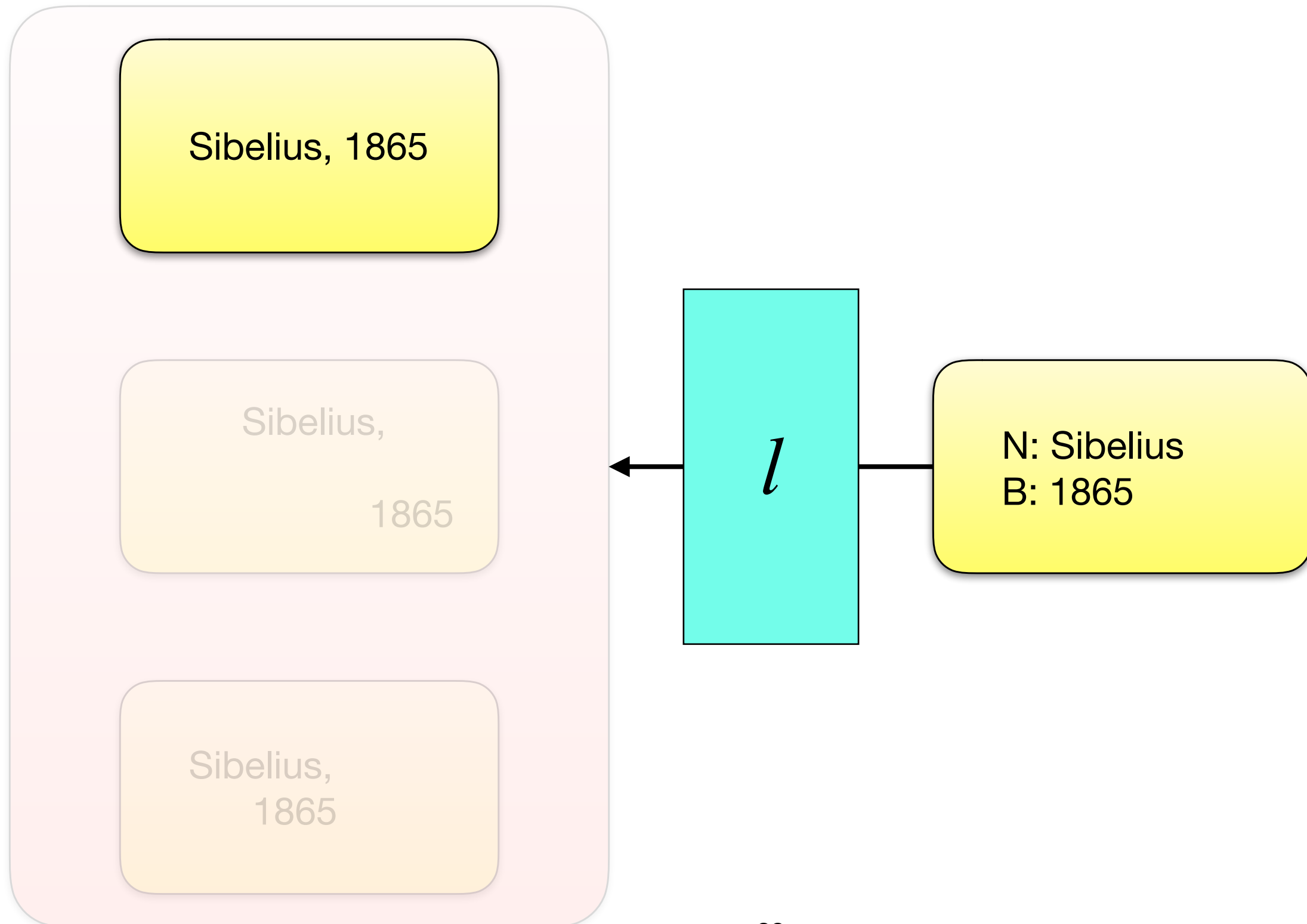
# Quotient Lenses



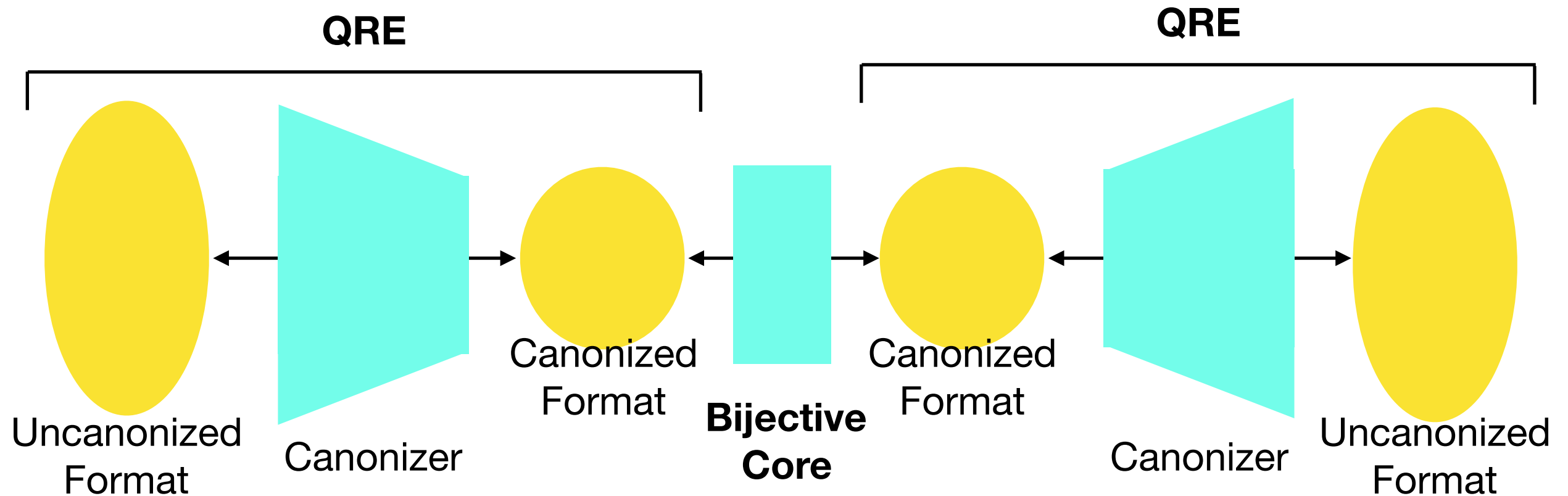
# Quotient Lenses



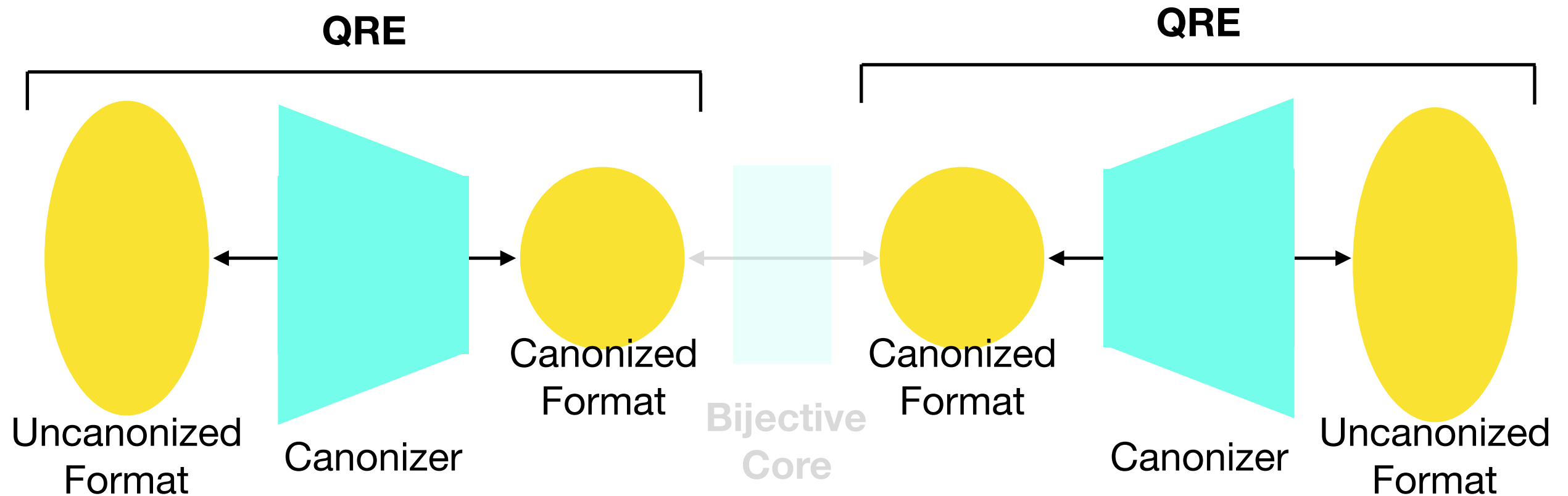
# Quotient Lenses



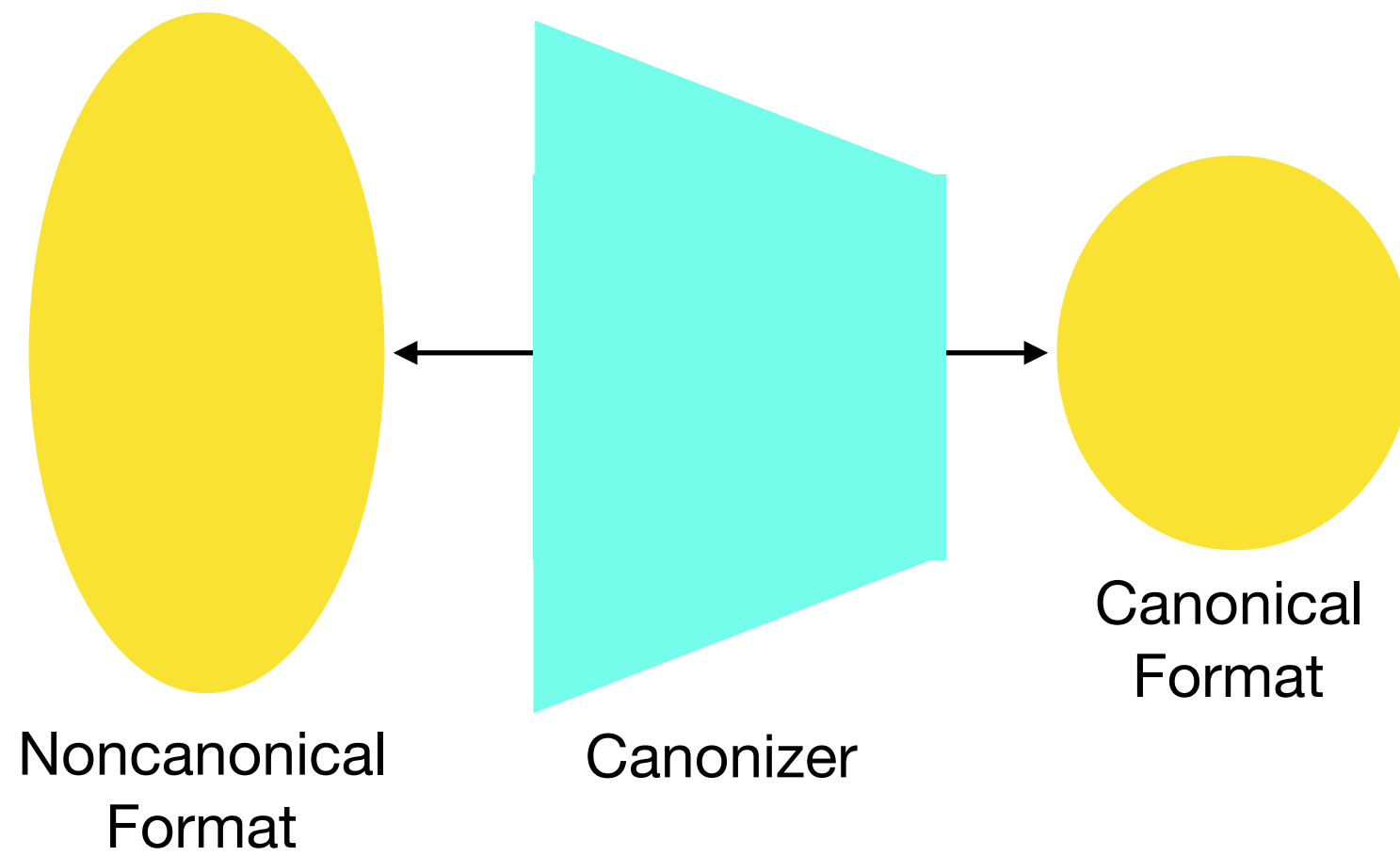
# Quotient Lens Synthesis



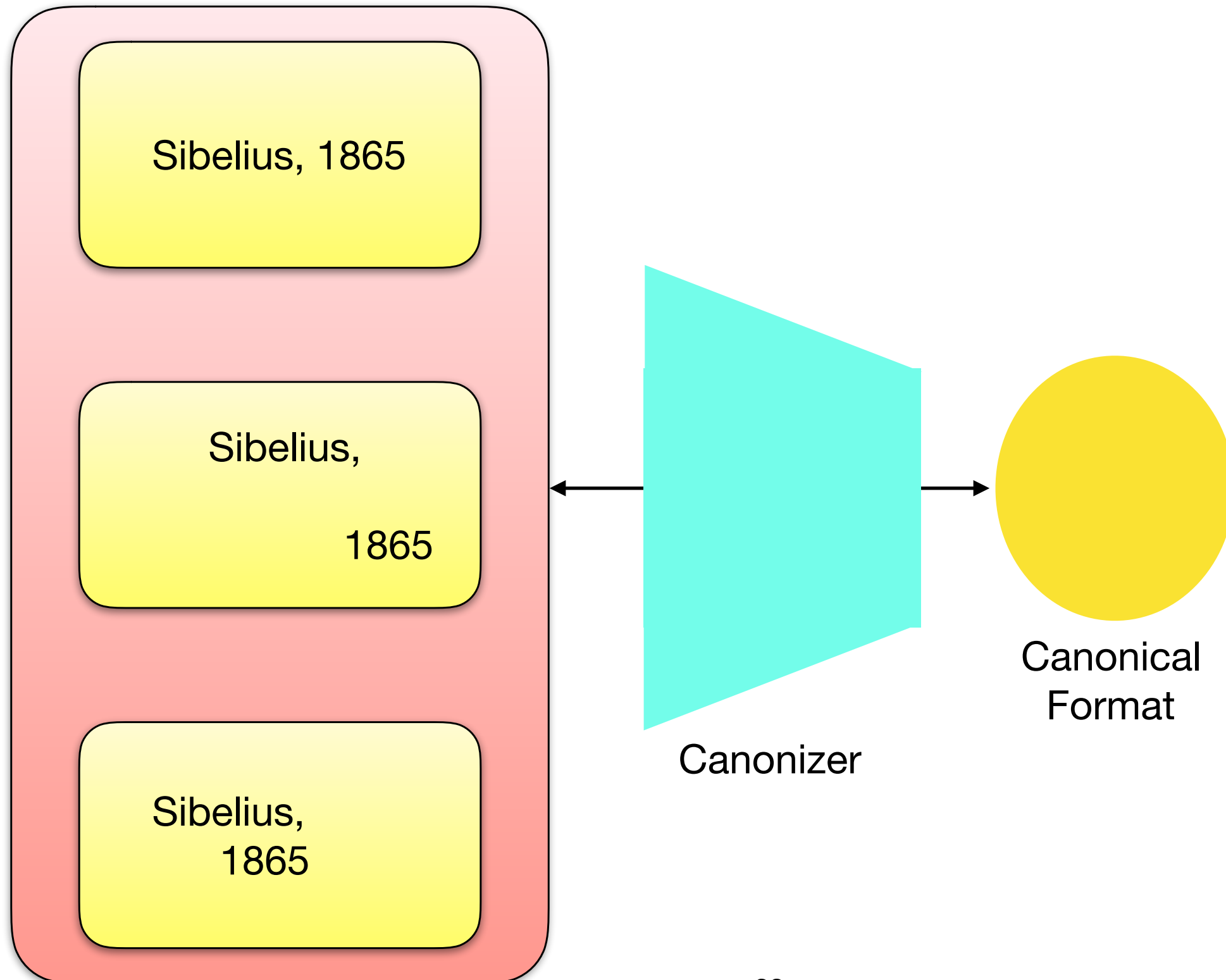
# Quotient Lens Synthesis



# QRE

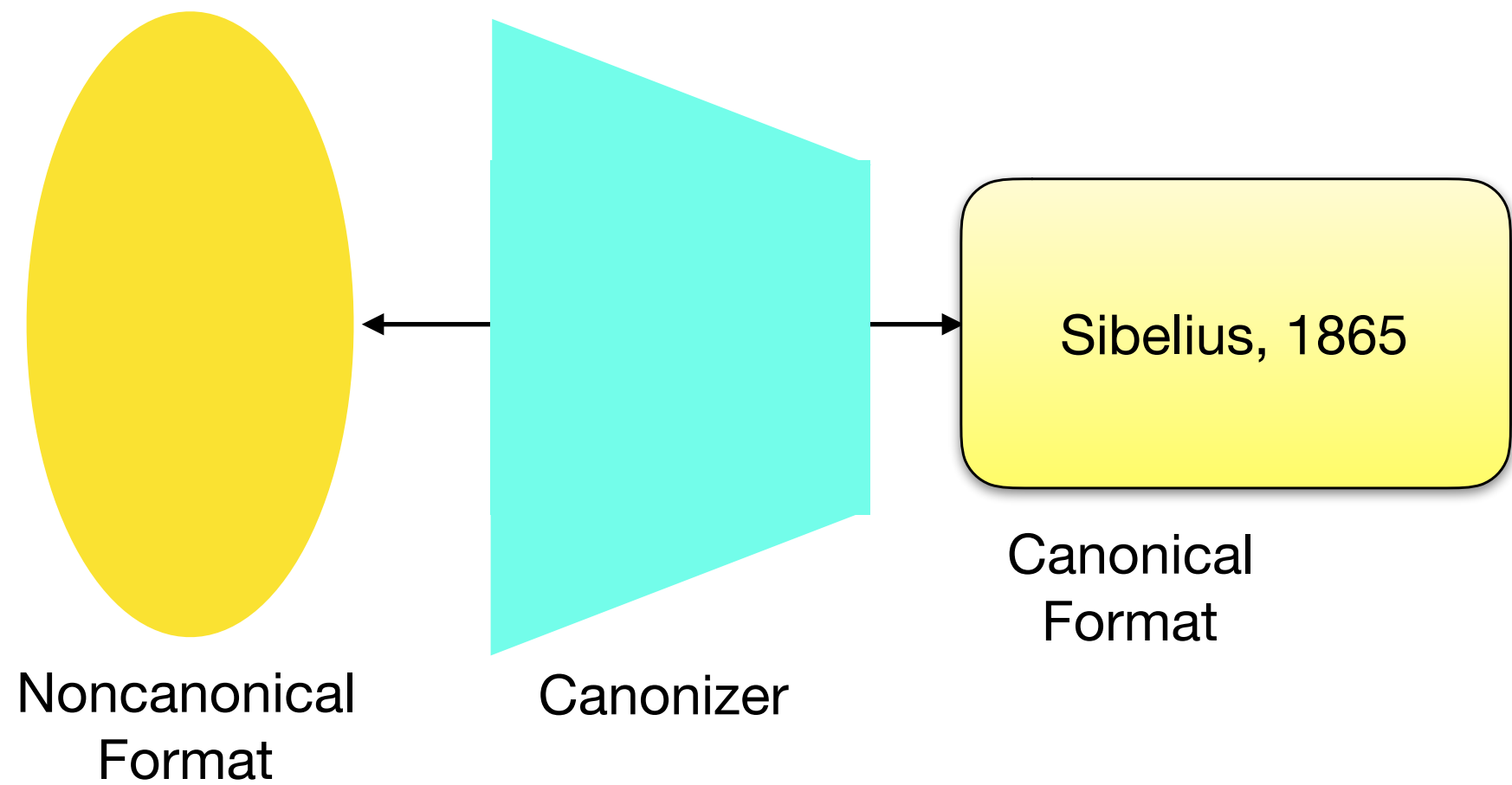


# QRE

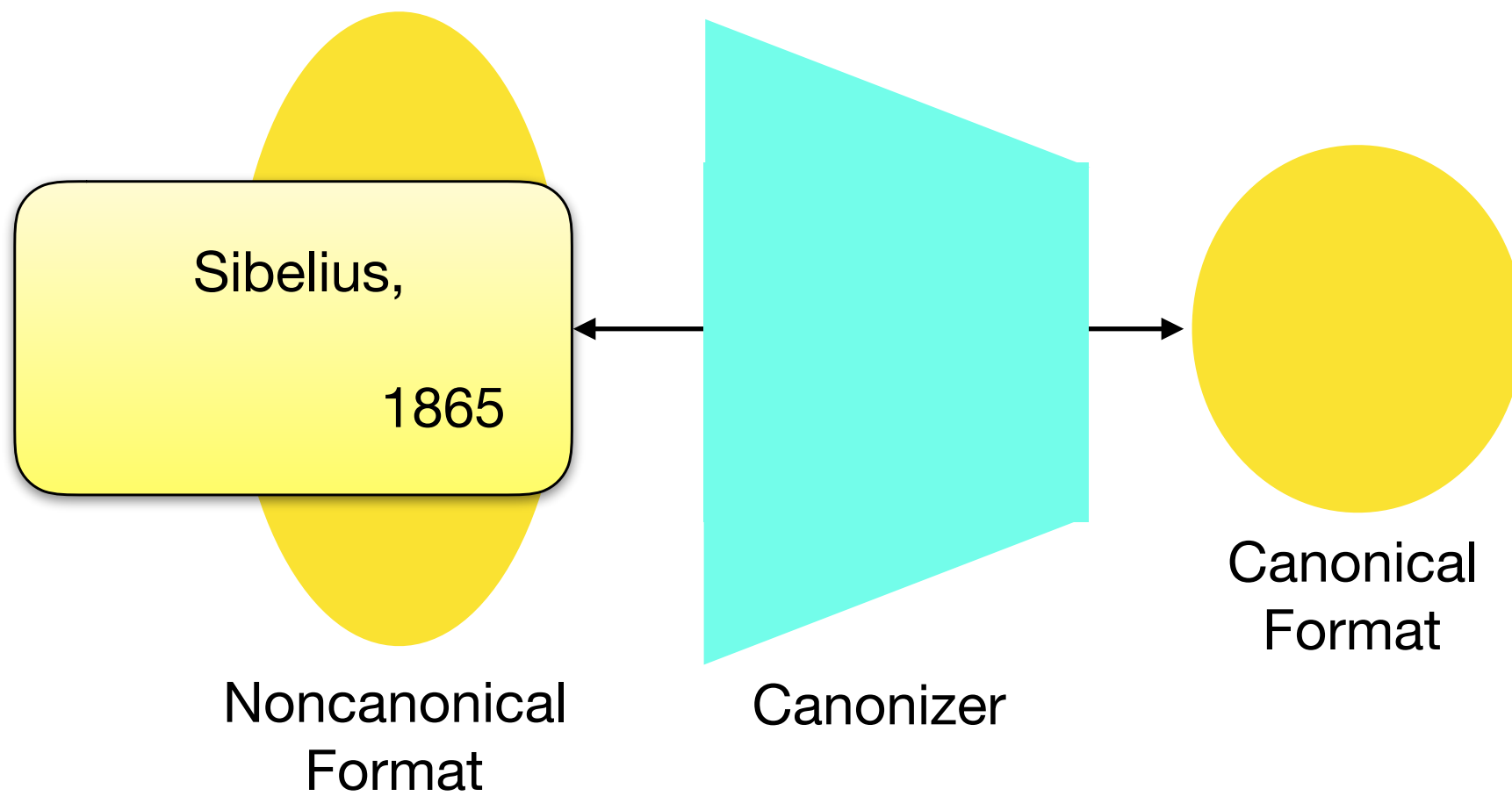




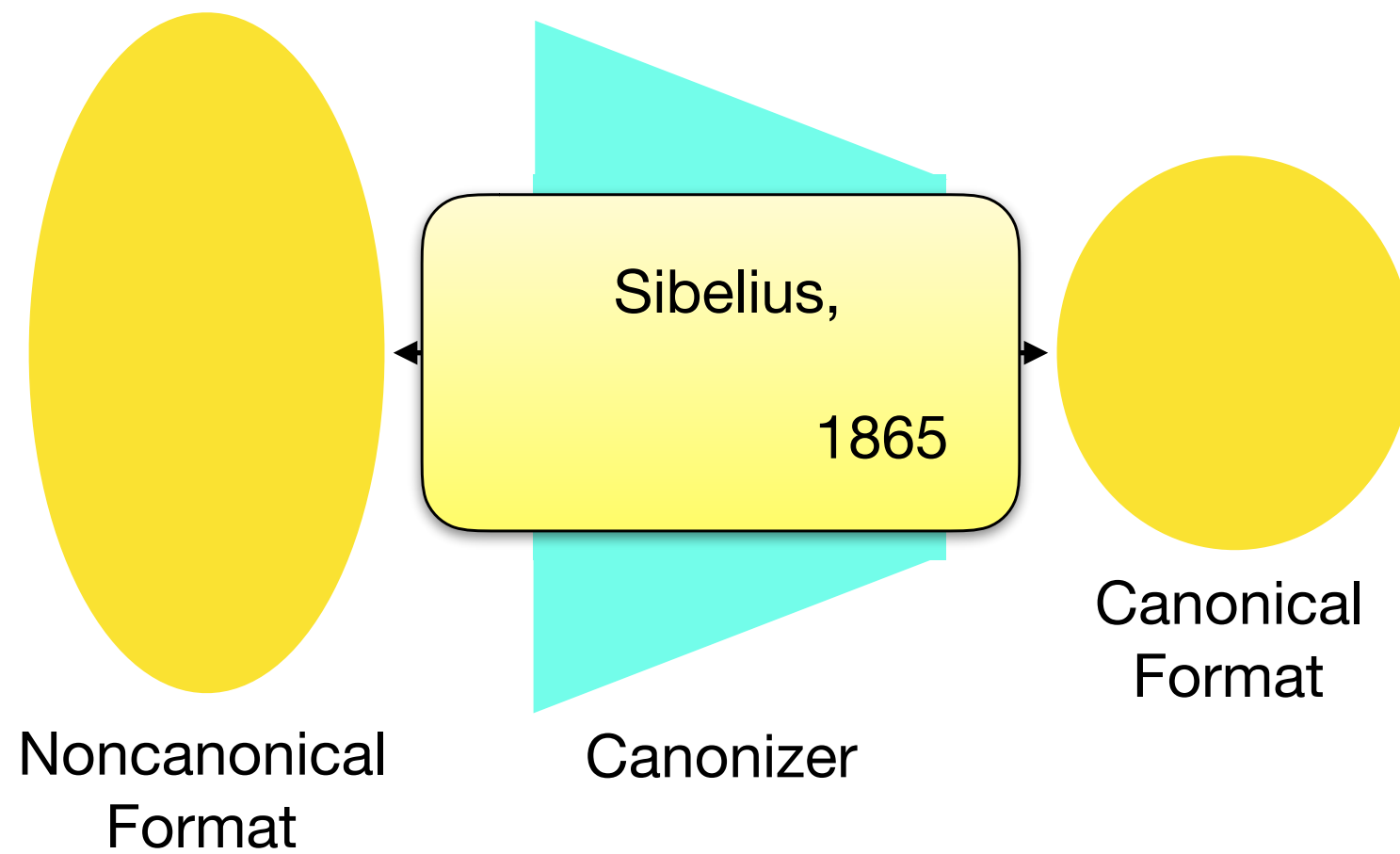
# QRE



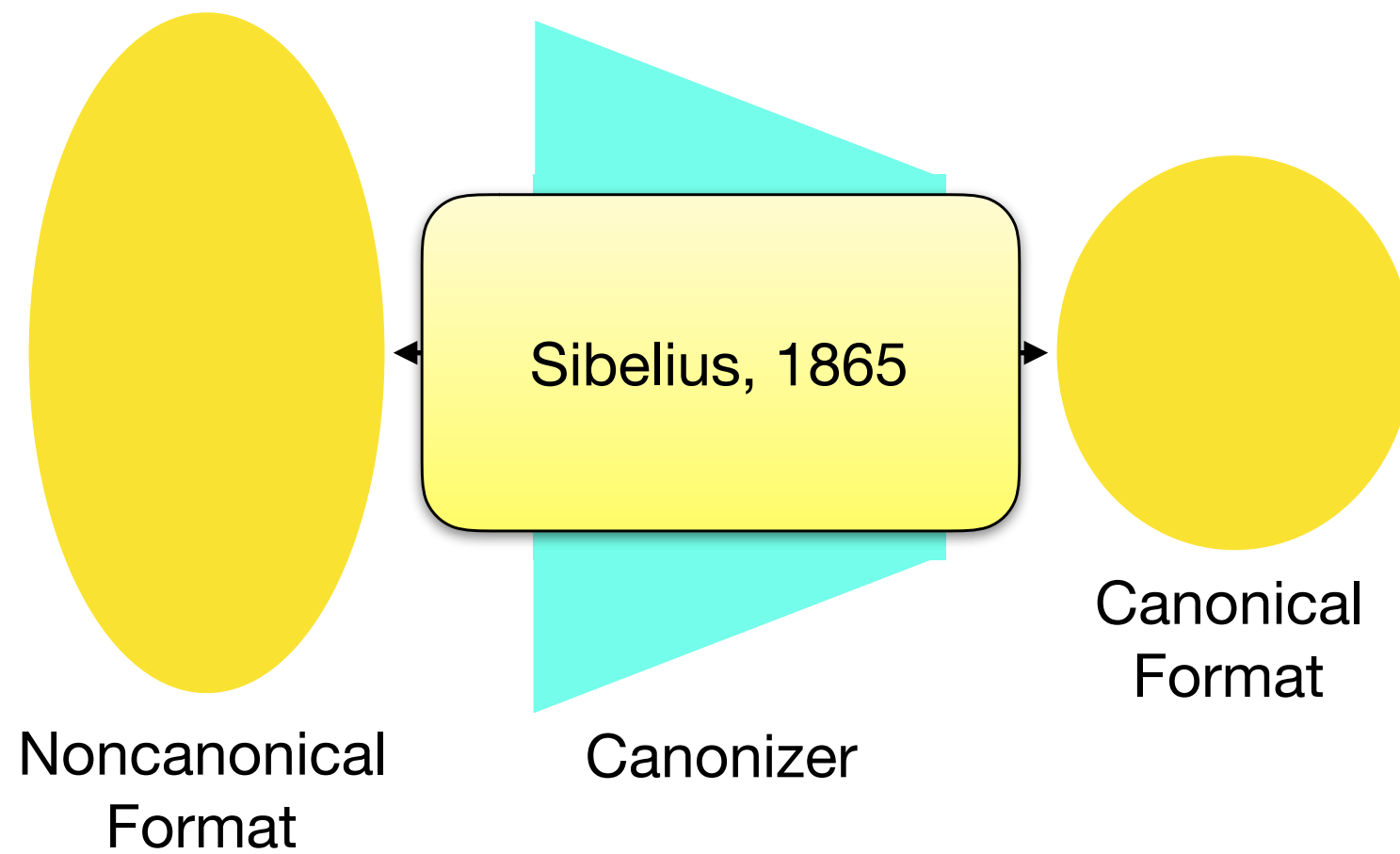
# QRE



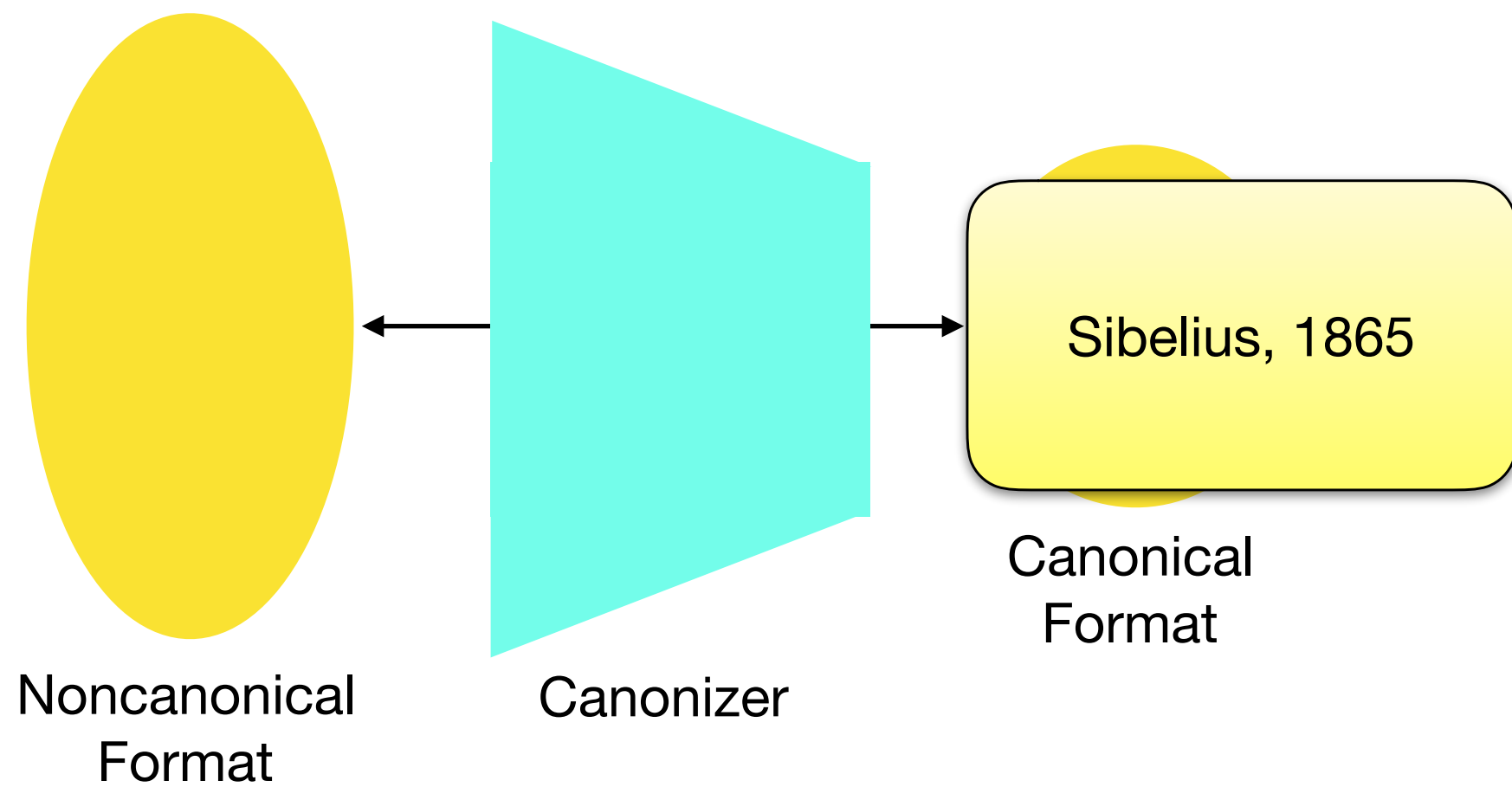
# QRE



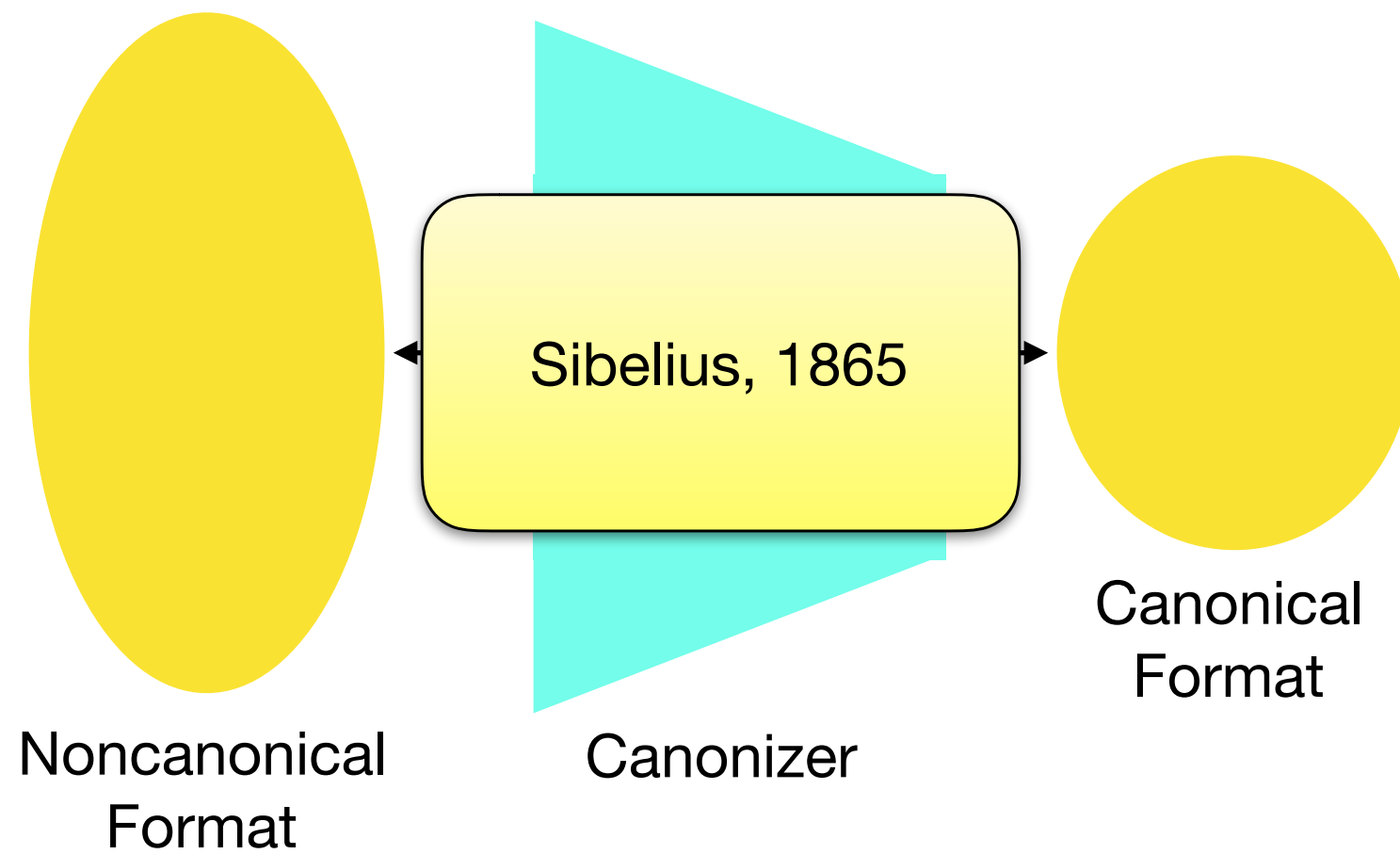
# QRE



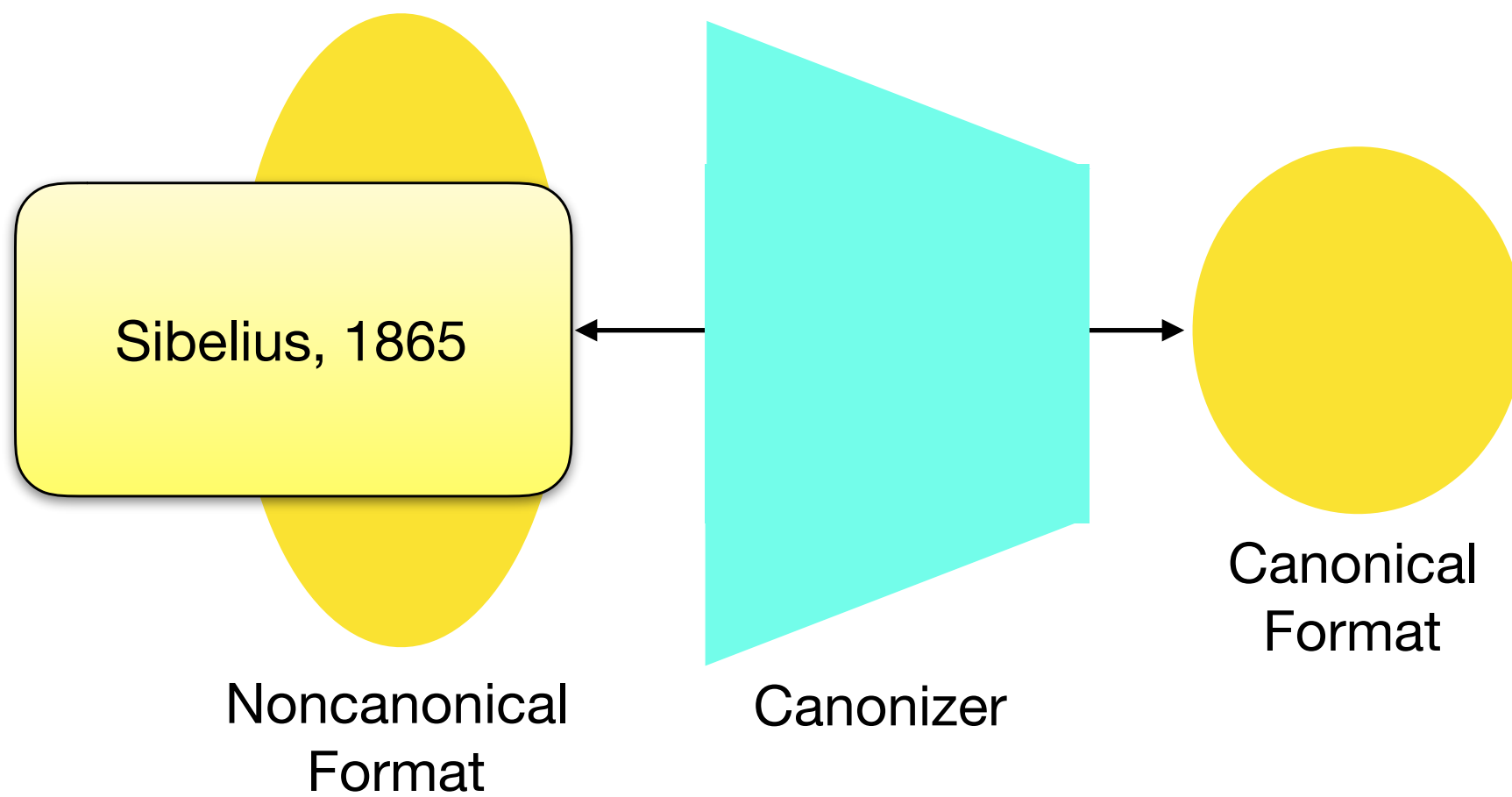
# QRE



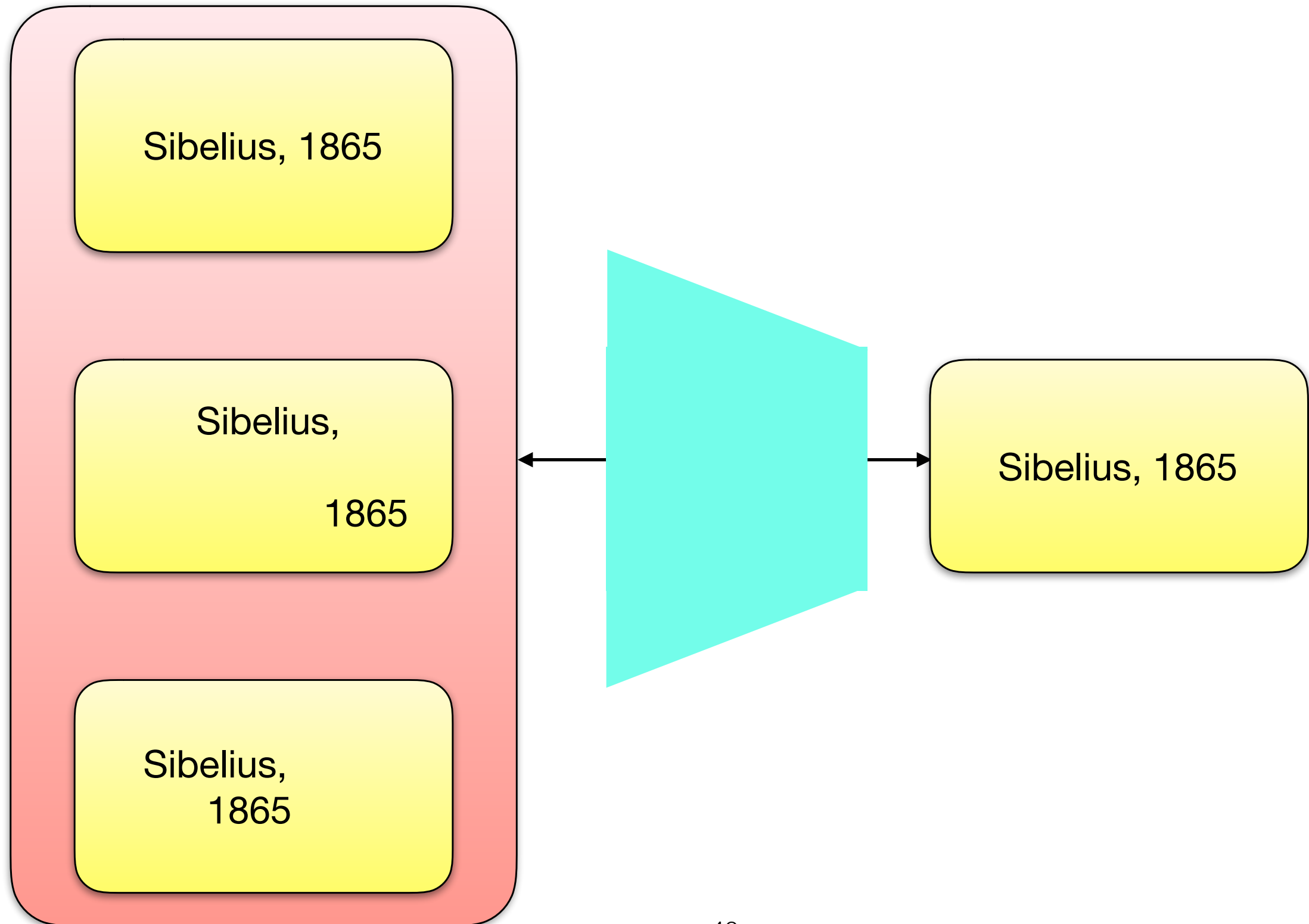
# QRE



# QRE

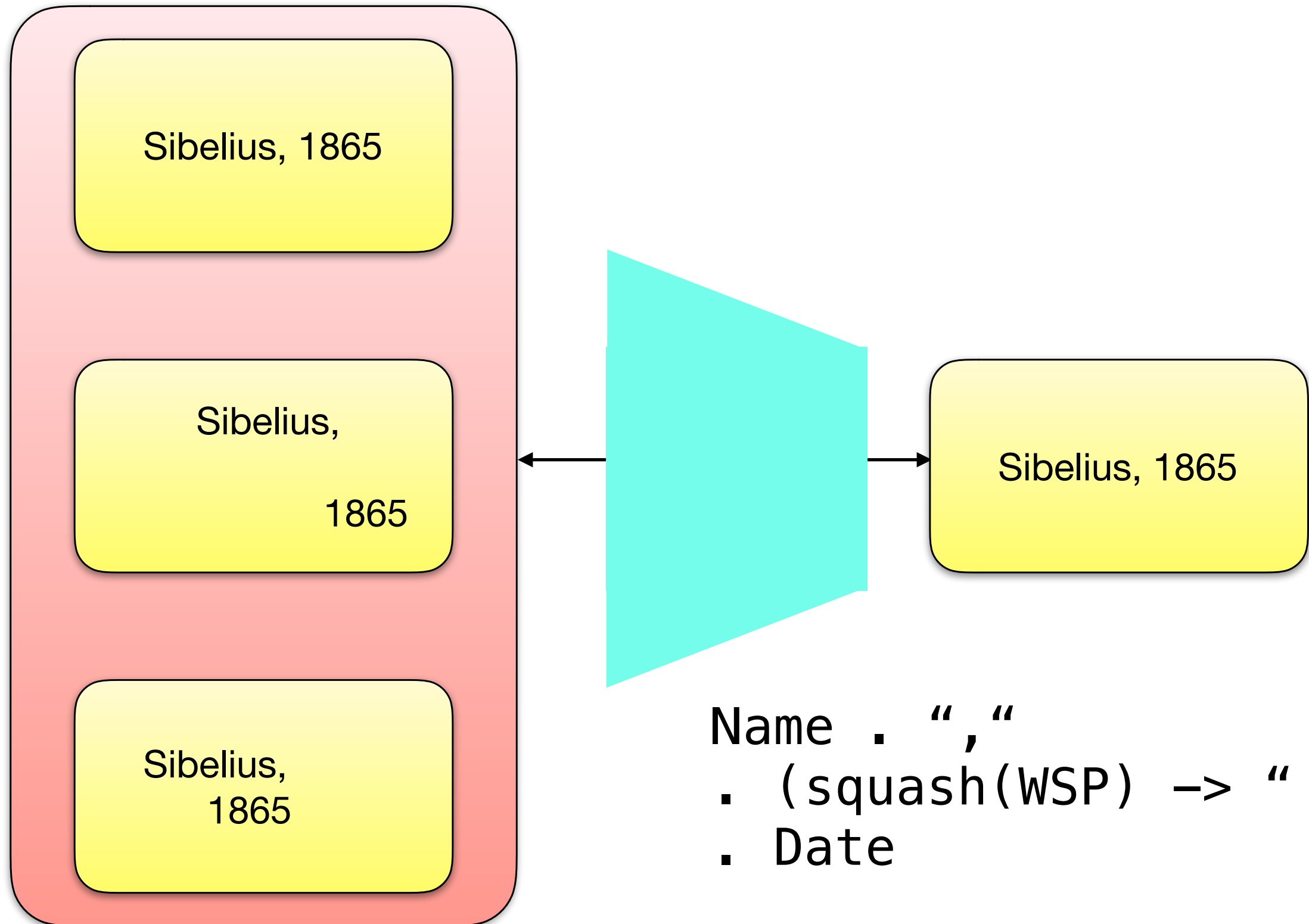


# QRE

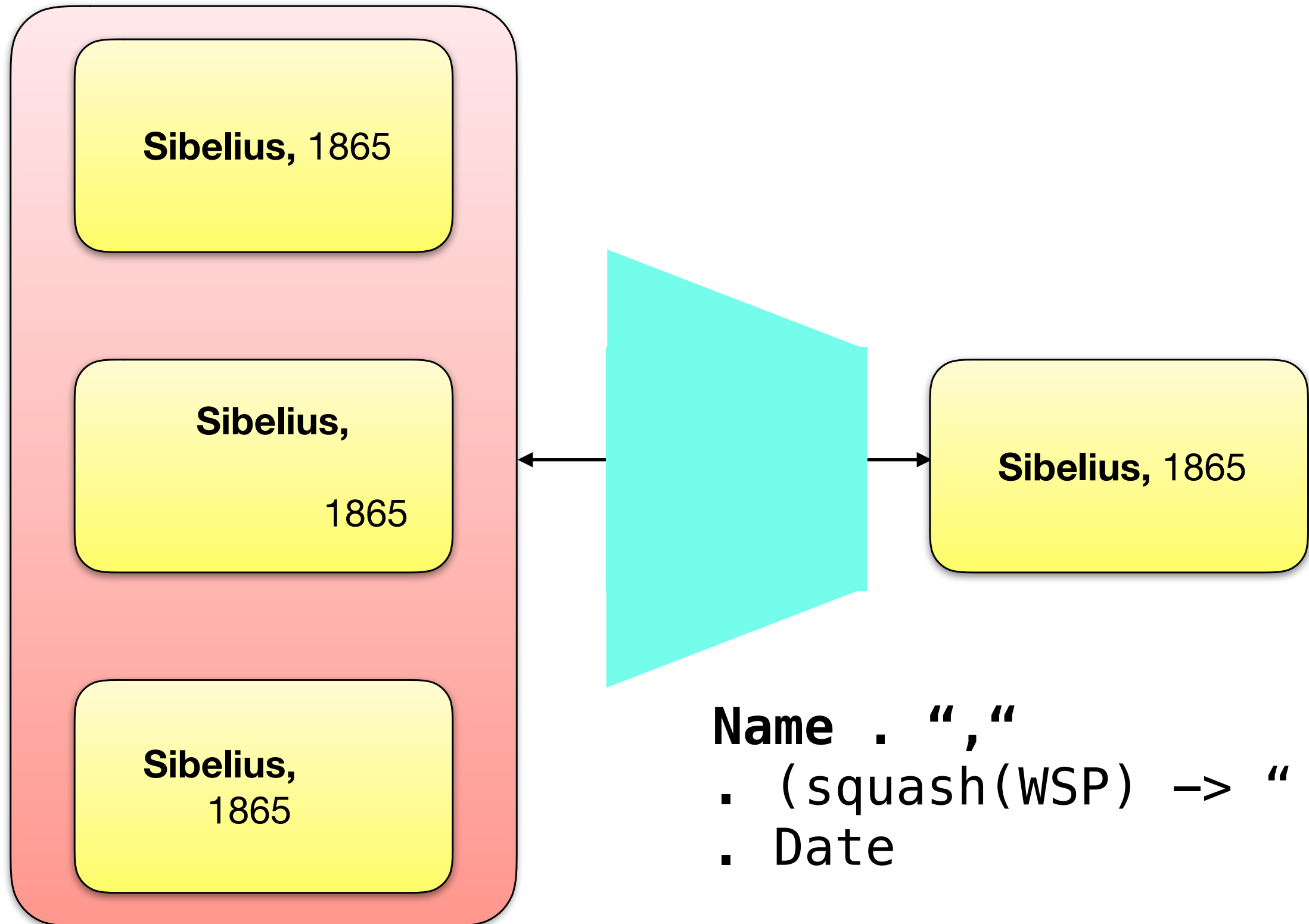




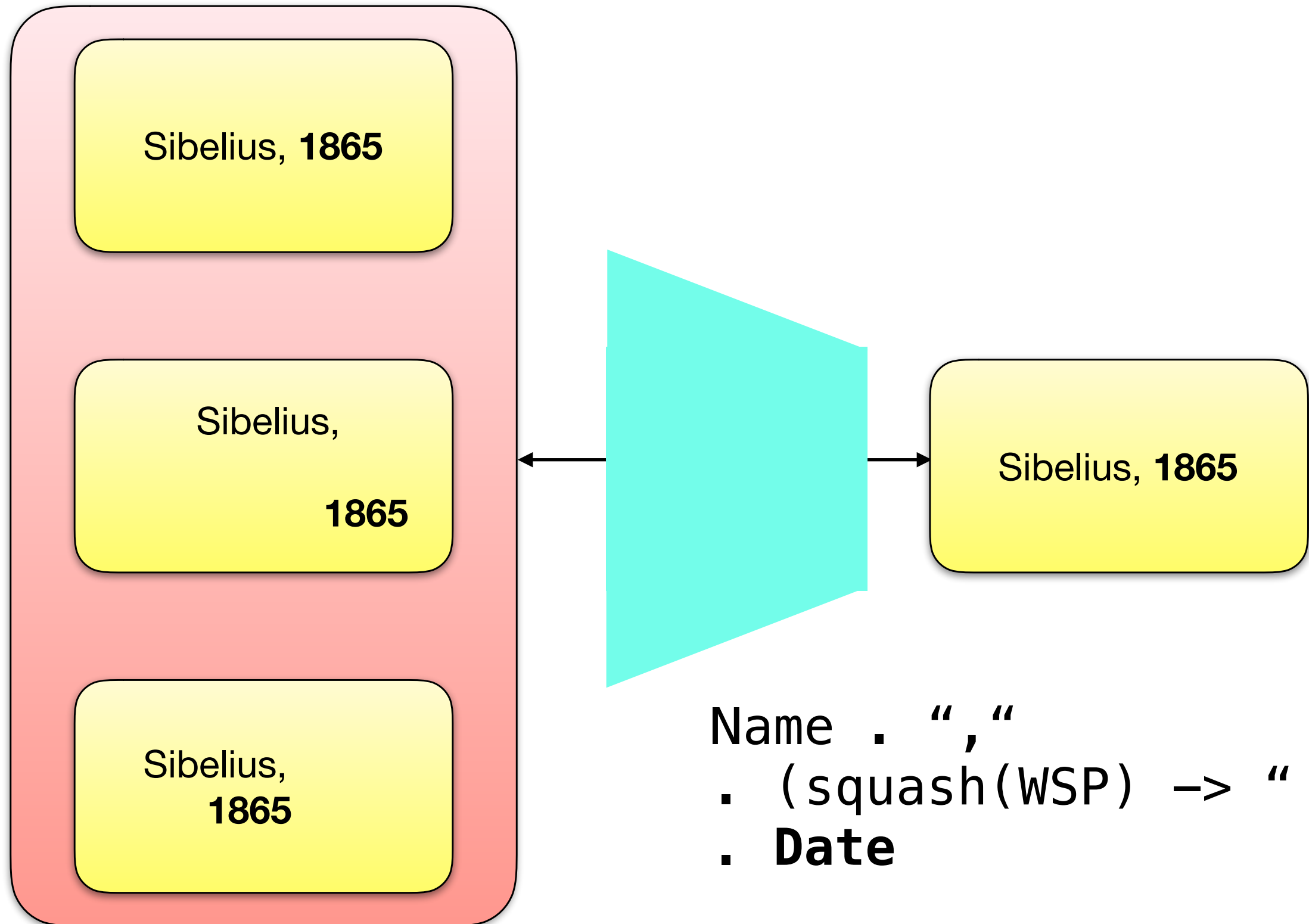
# QRE



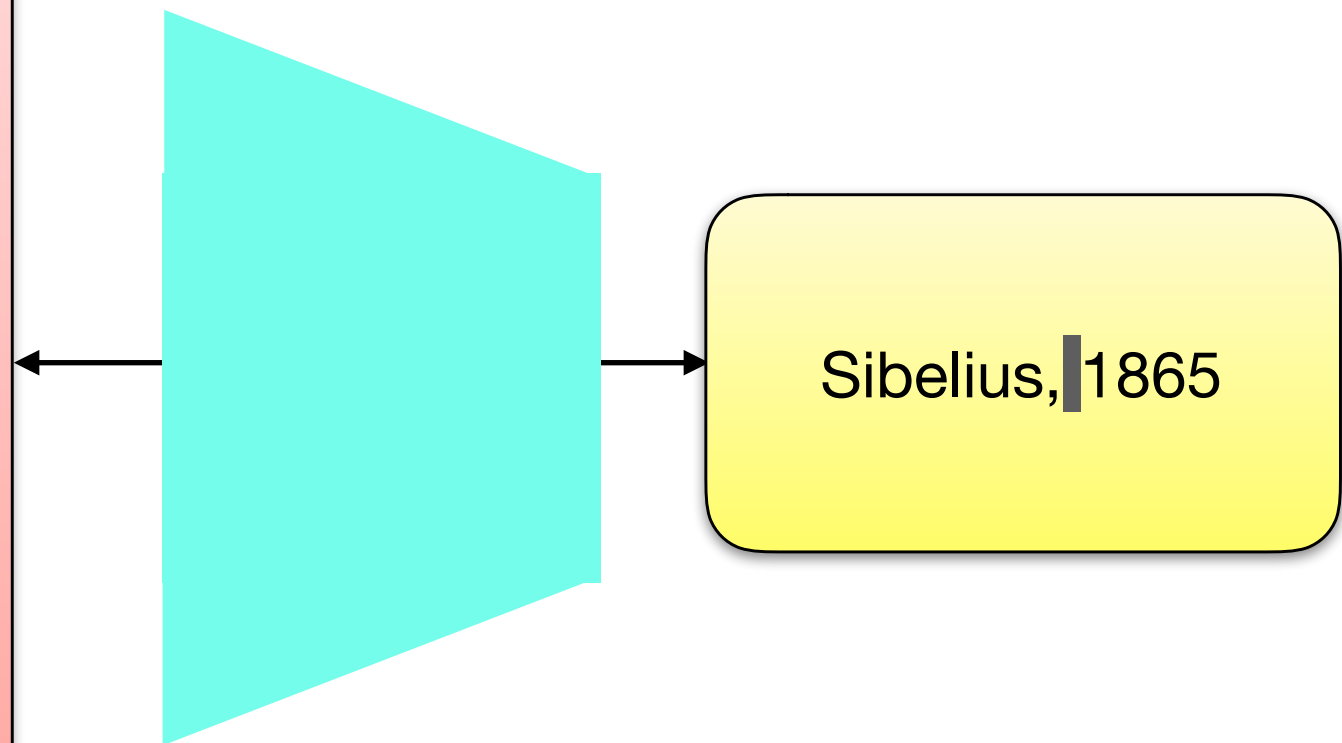
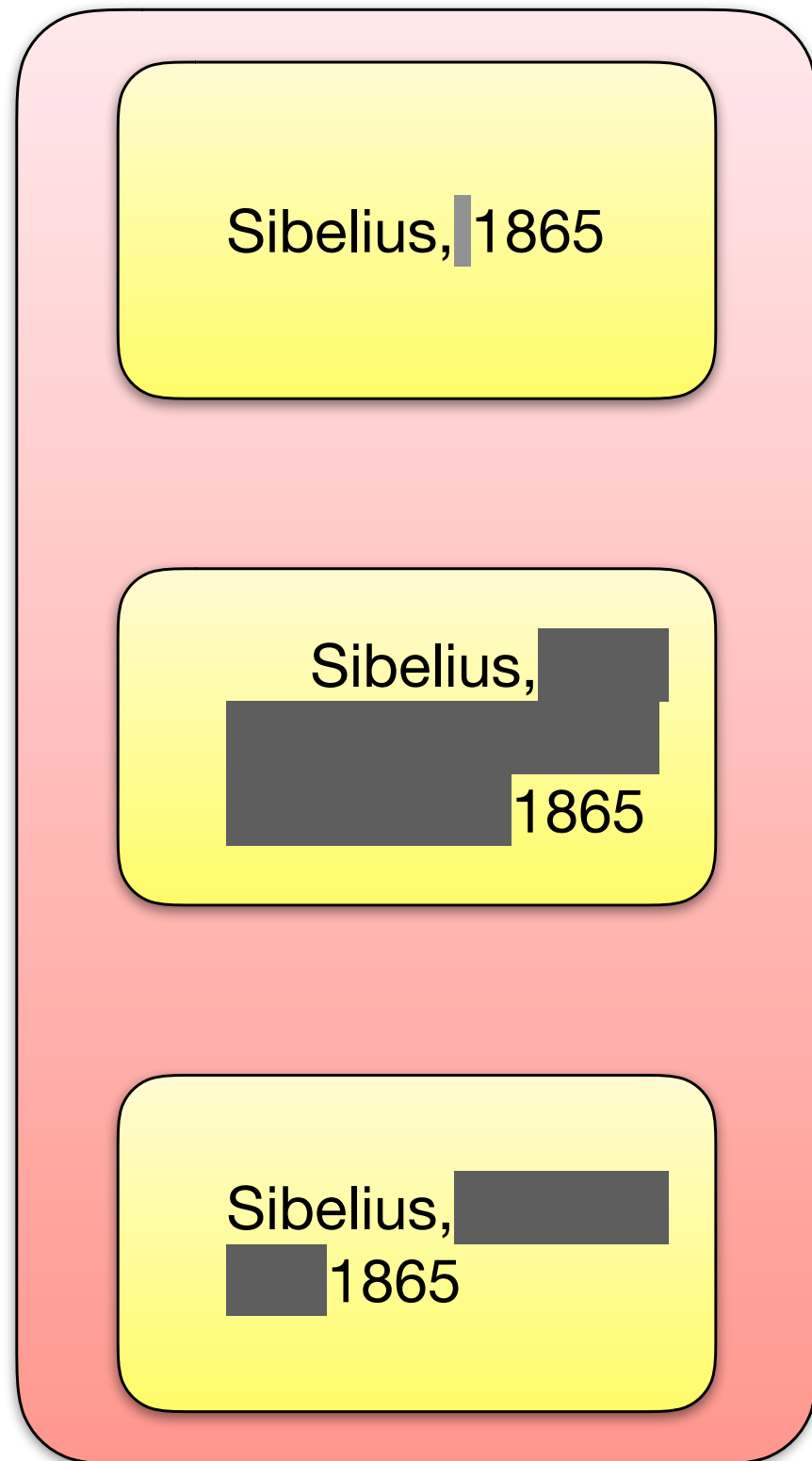
# QRE



# QRE

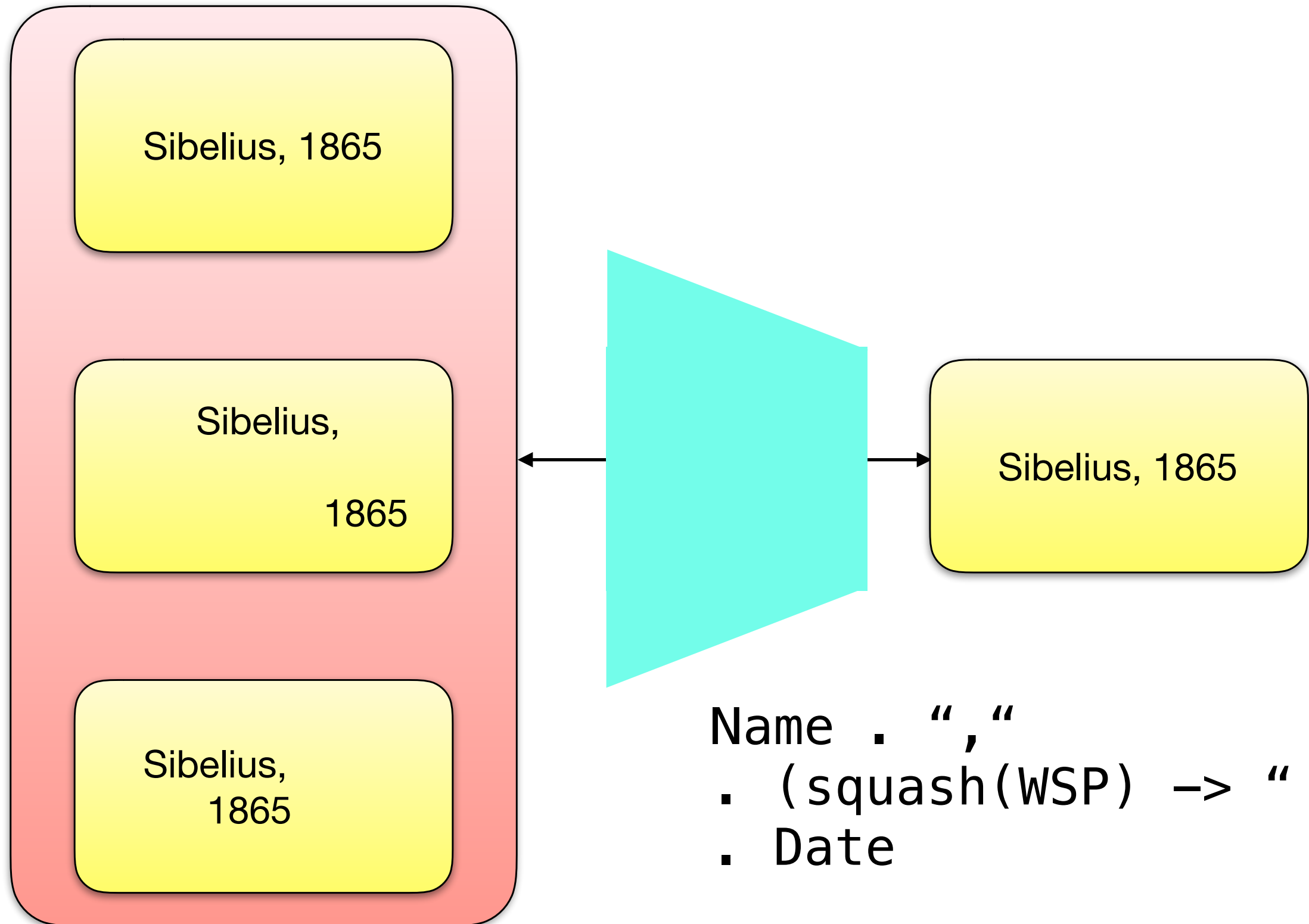


# QRE



Name . “ , “  
 . (squash(WSP) -> “ “)  
 . Date

# QRE



Name . “,”  
▪ WSP  
▪ Date

# QRE

Sibelius, 1865

Sibelius,  
1865

Sibelius,  
1865

Name . “,”  
▪ “ ”  
▪ Date

Sibelius, 1865

Name . “,”  
▪ (squash(WSP) → “ ”)  
▪ Date

Name . " , "  
.  
WSP  
.  
Date

# QRE

Sibelius, 1865

Sibelius,  
1865

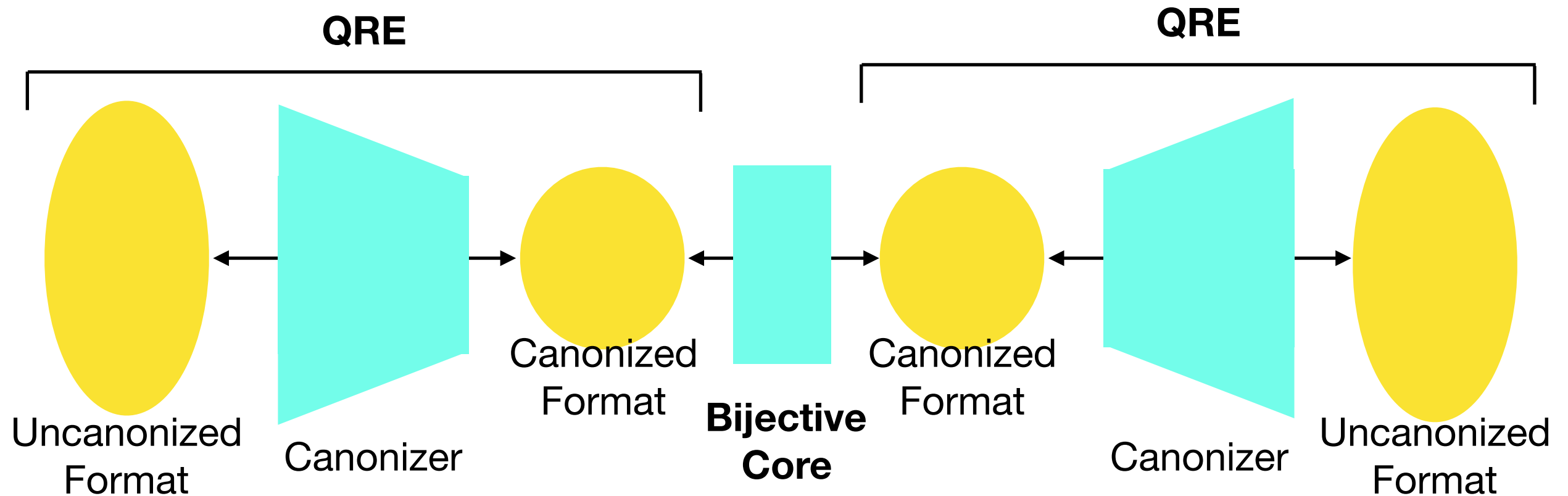
Sibelius,  
1865

Name . " , "  
.  
" "  
.  
Date

Sibelius, 1865

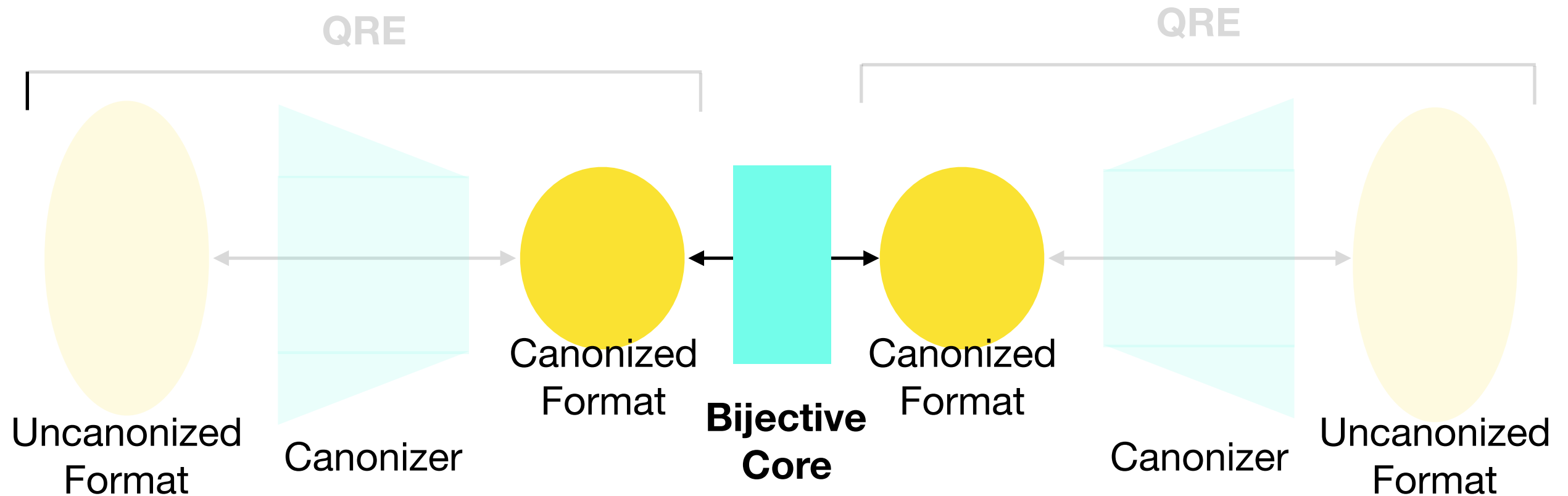
Name . " , "  
.  
(squash(WSP) -> " ")  
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Date

# Quotient Lens Synthesis



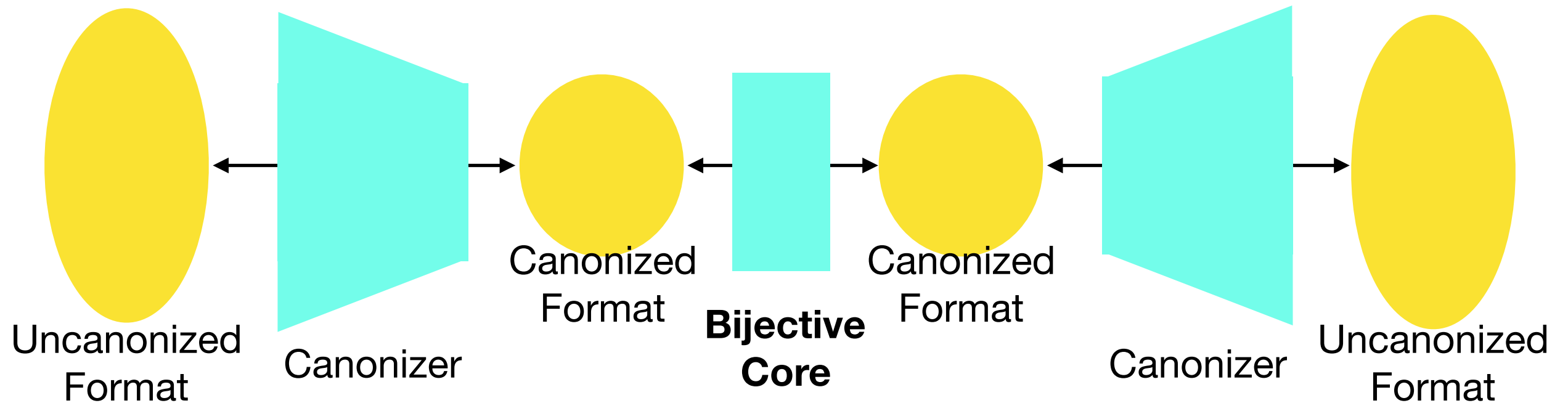


# Quotient Lens Synthesis



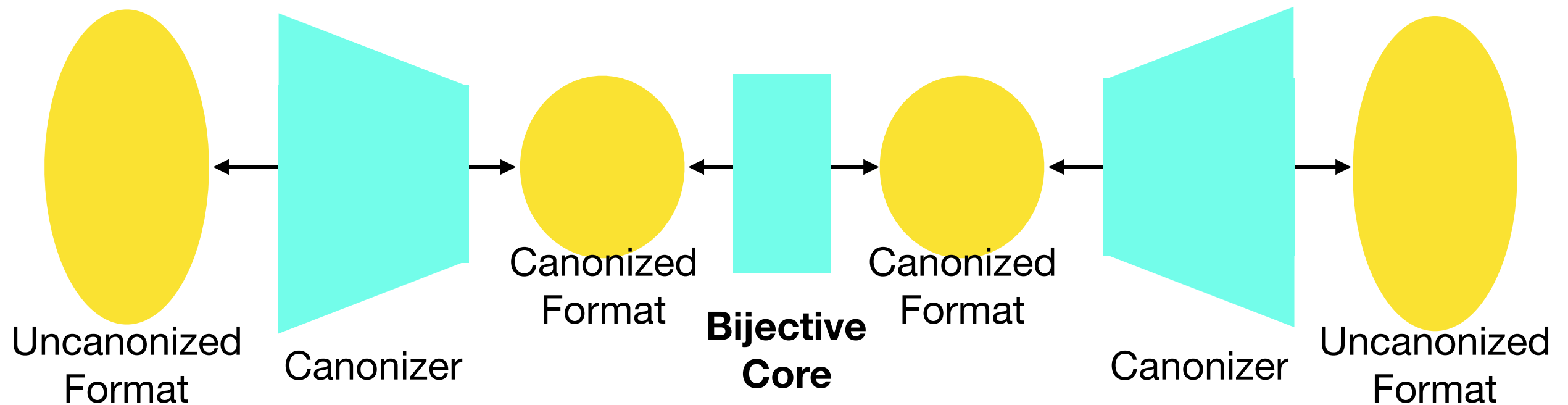
# Quotient Lens Synthesis

Sibelius,  
1865



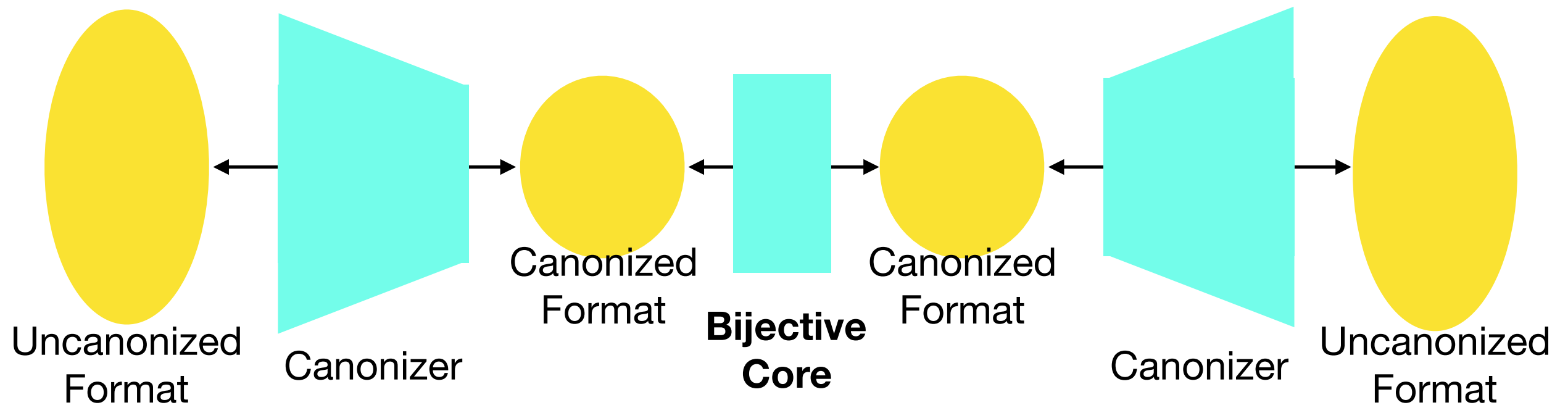
# Quotient Lens Synthesis

Sibelius,  
1865

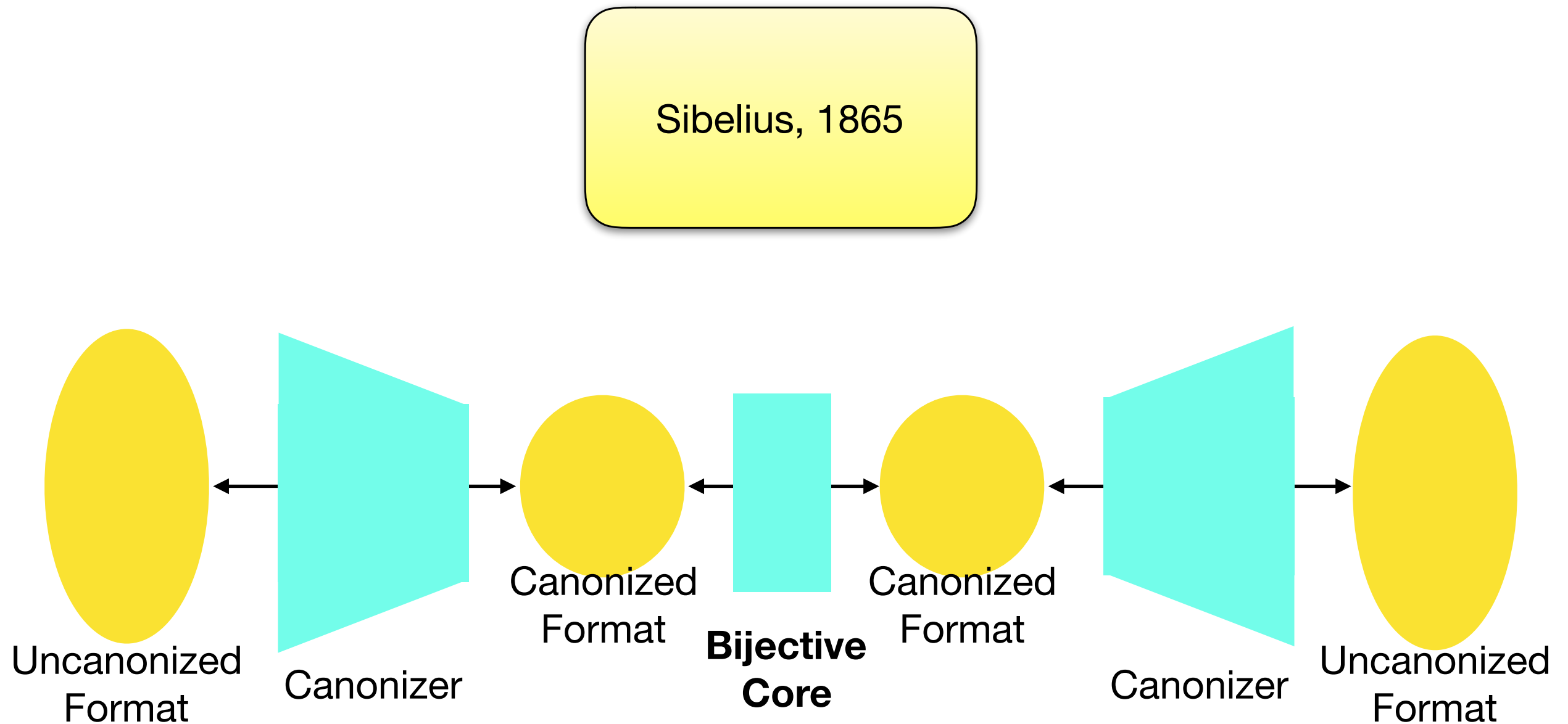


# Quotient Lens Synthesis

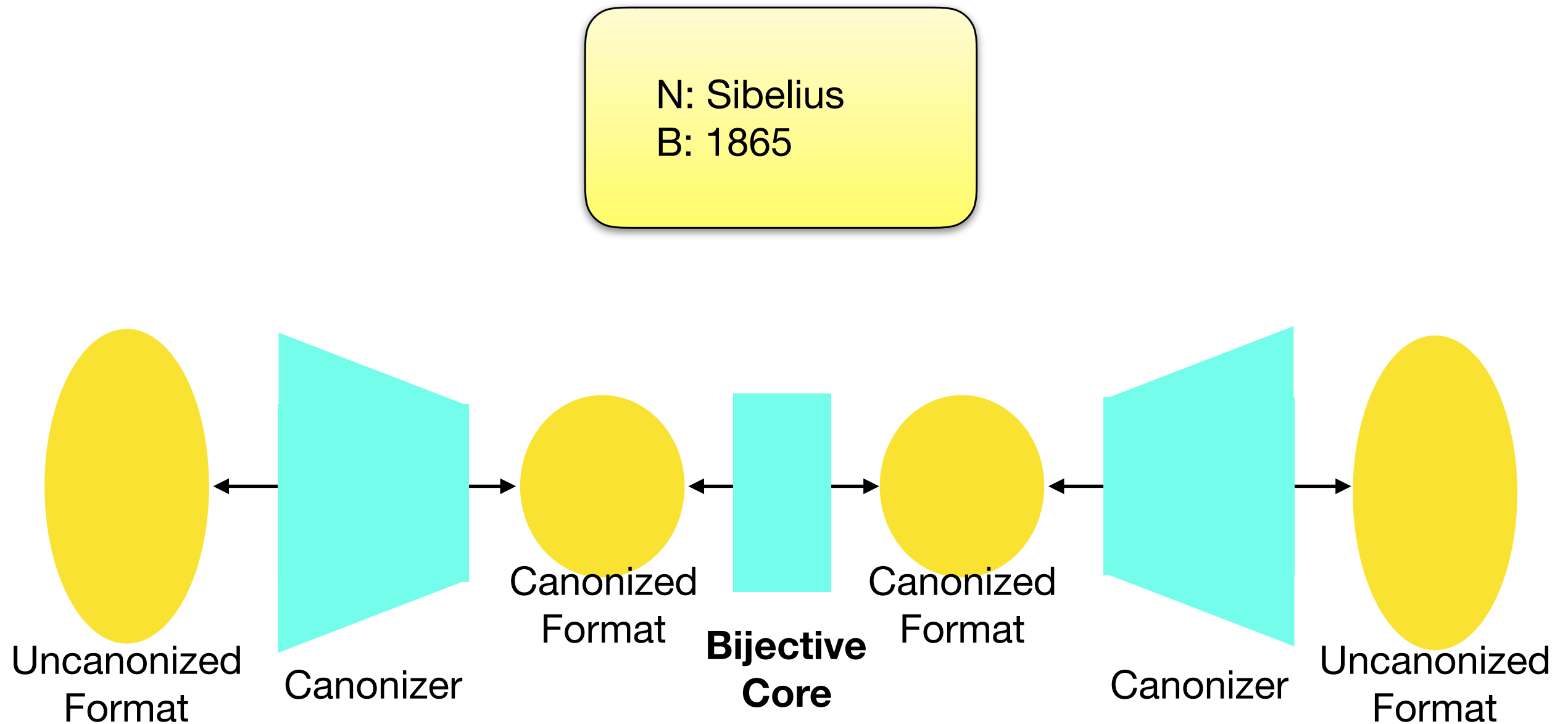
Sibelius, 1865



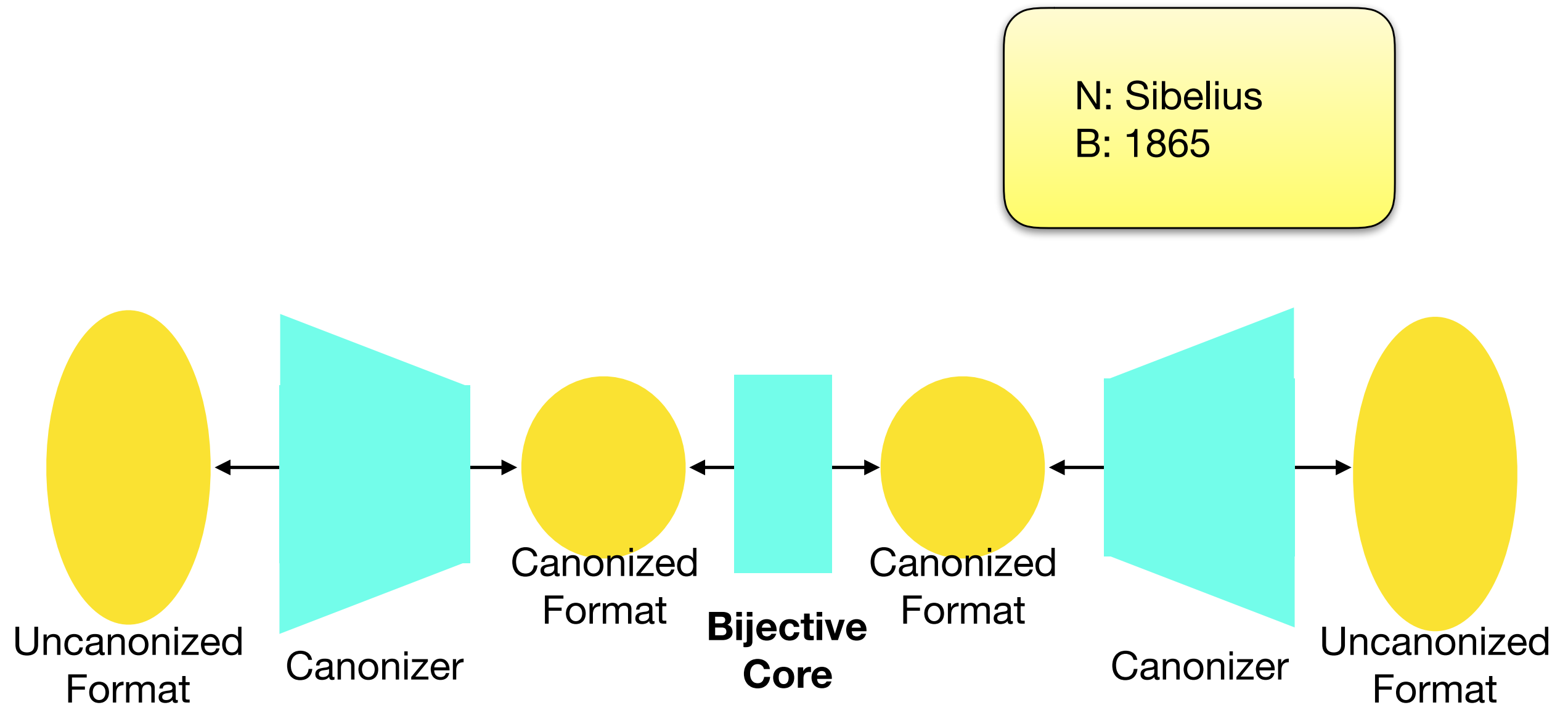
# Quotient Lens Synthesis



# Quotient Lens Synthesis

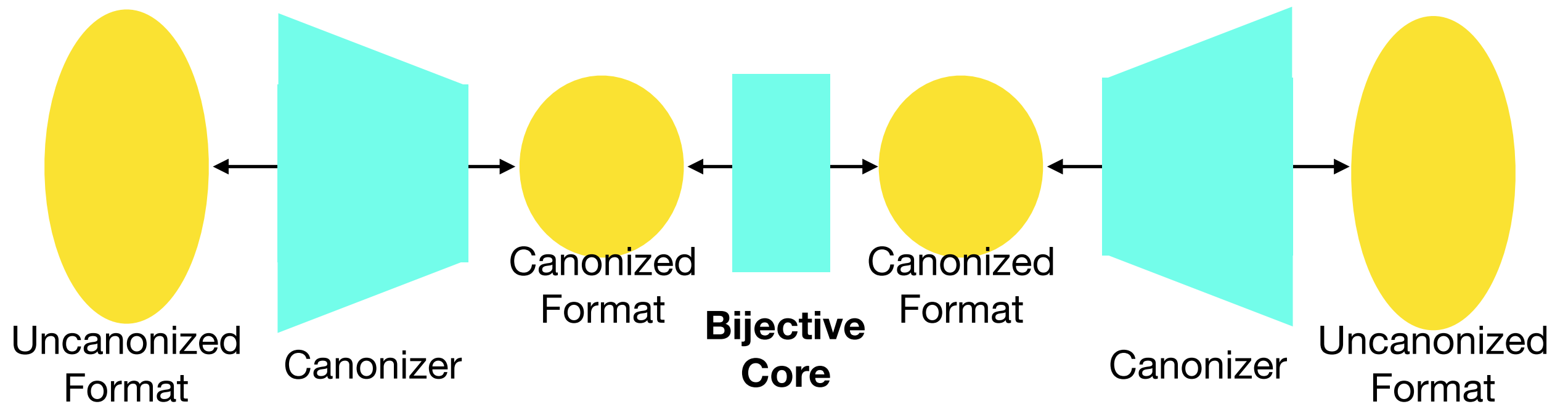


# Quotient Lens Synthesis



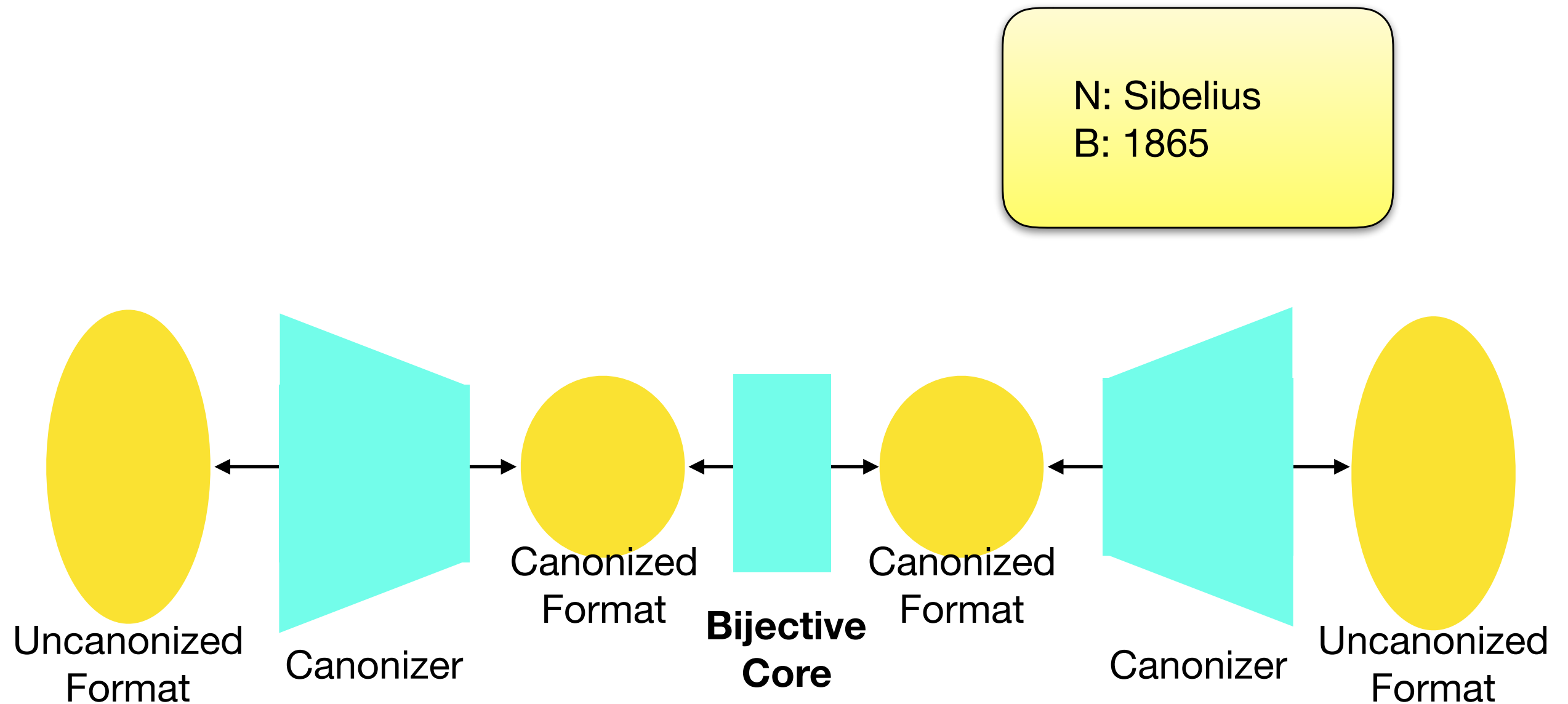
# Quotient Lens Synthesis

N: Sibelius  
B: 1865

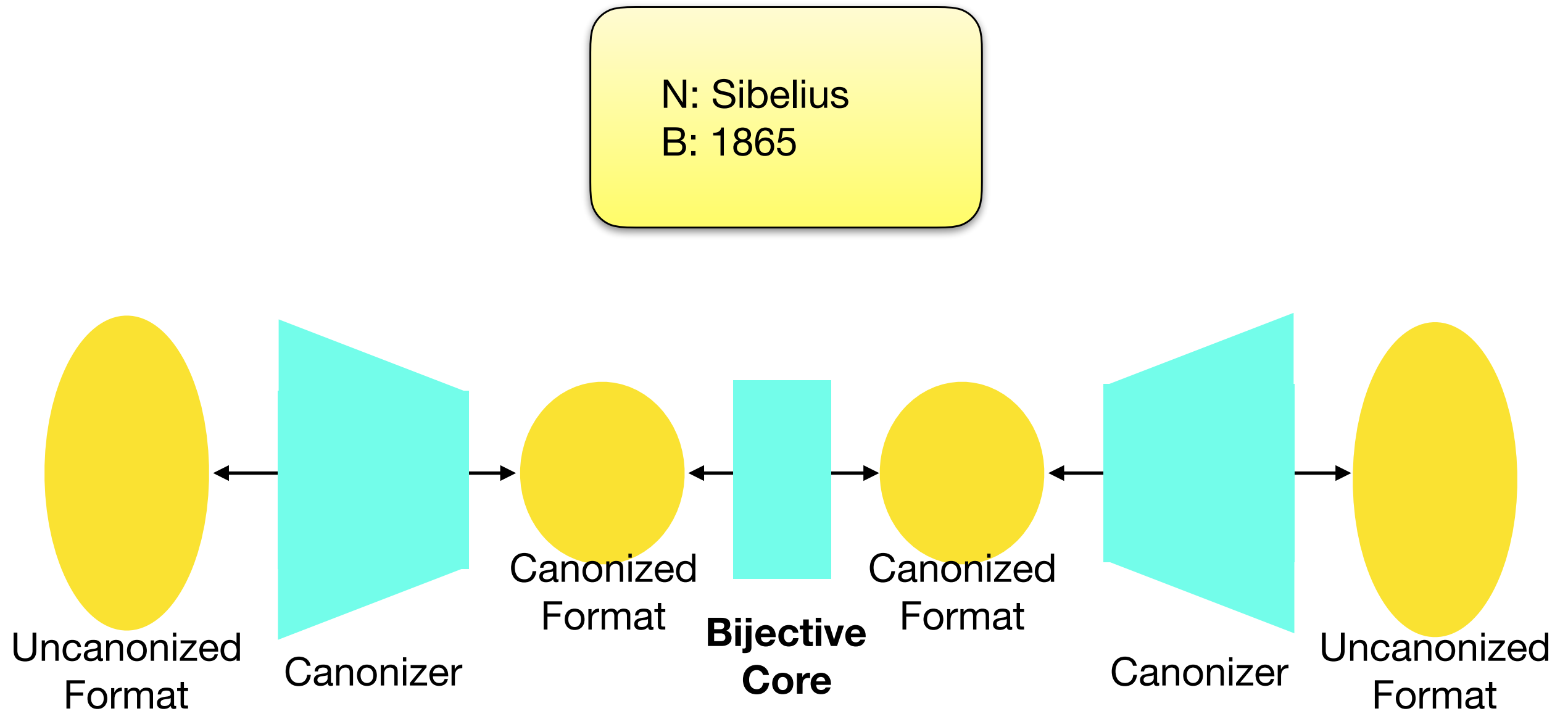




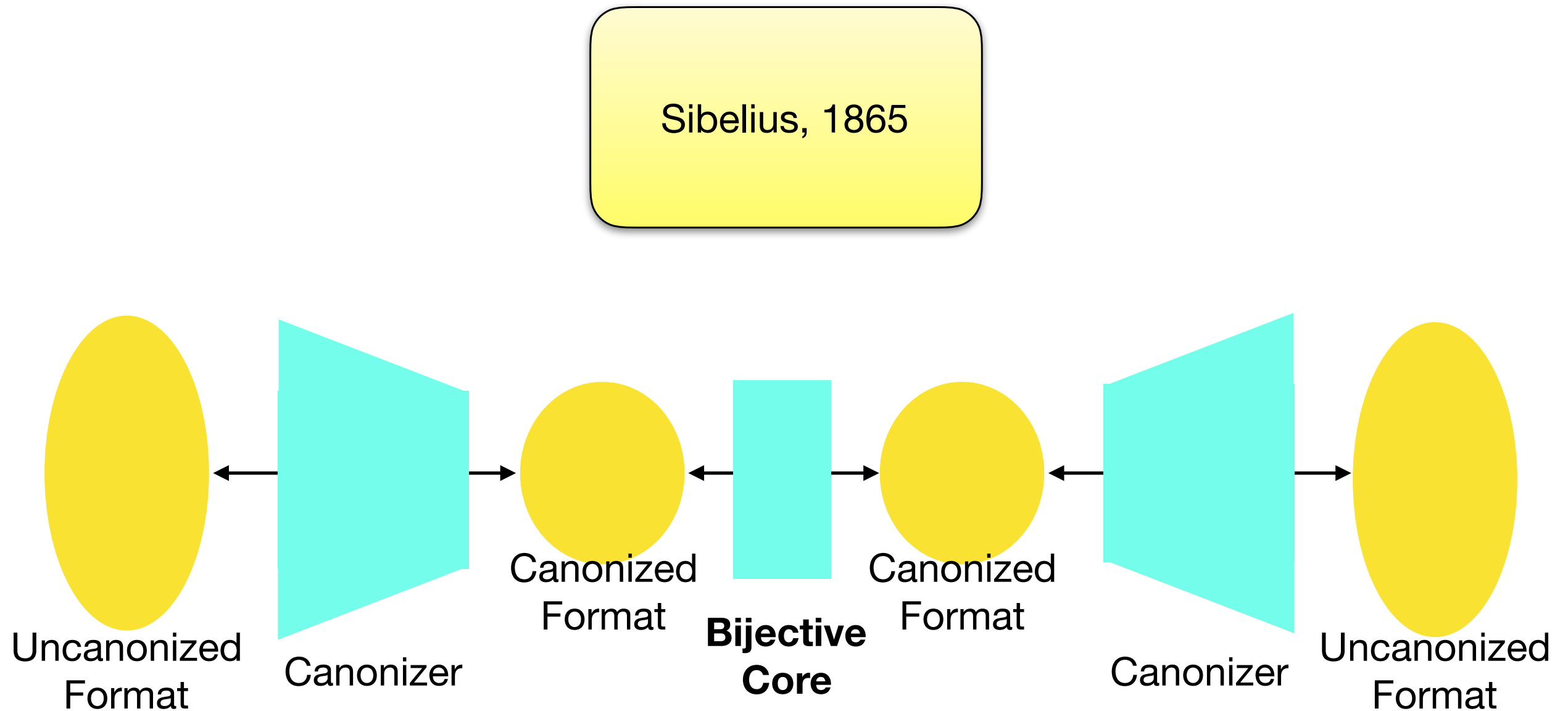
# Quotient Lens Synthesis



# Quotient Lens Synthesis

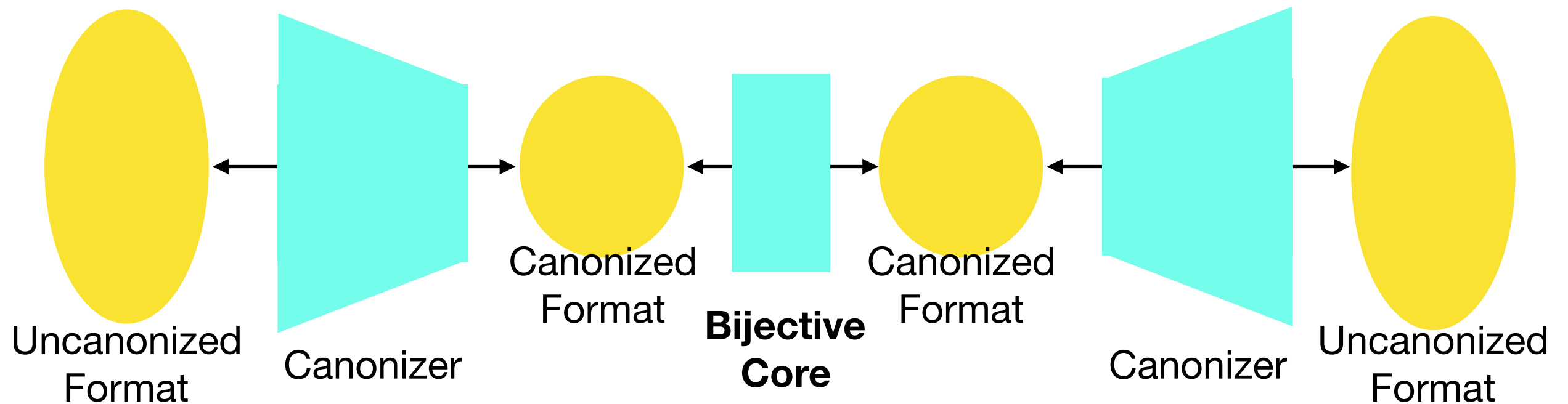


# Quotient Lens Synthesis



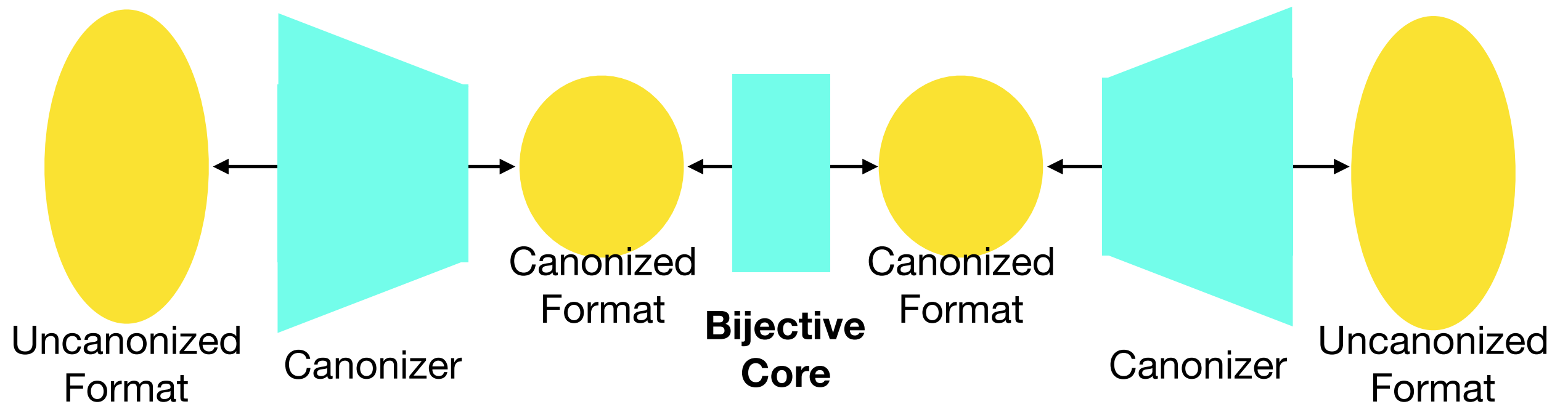
# Quotient Lens Synthesis

Sibelius, 1865

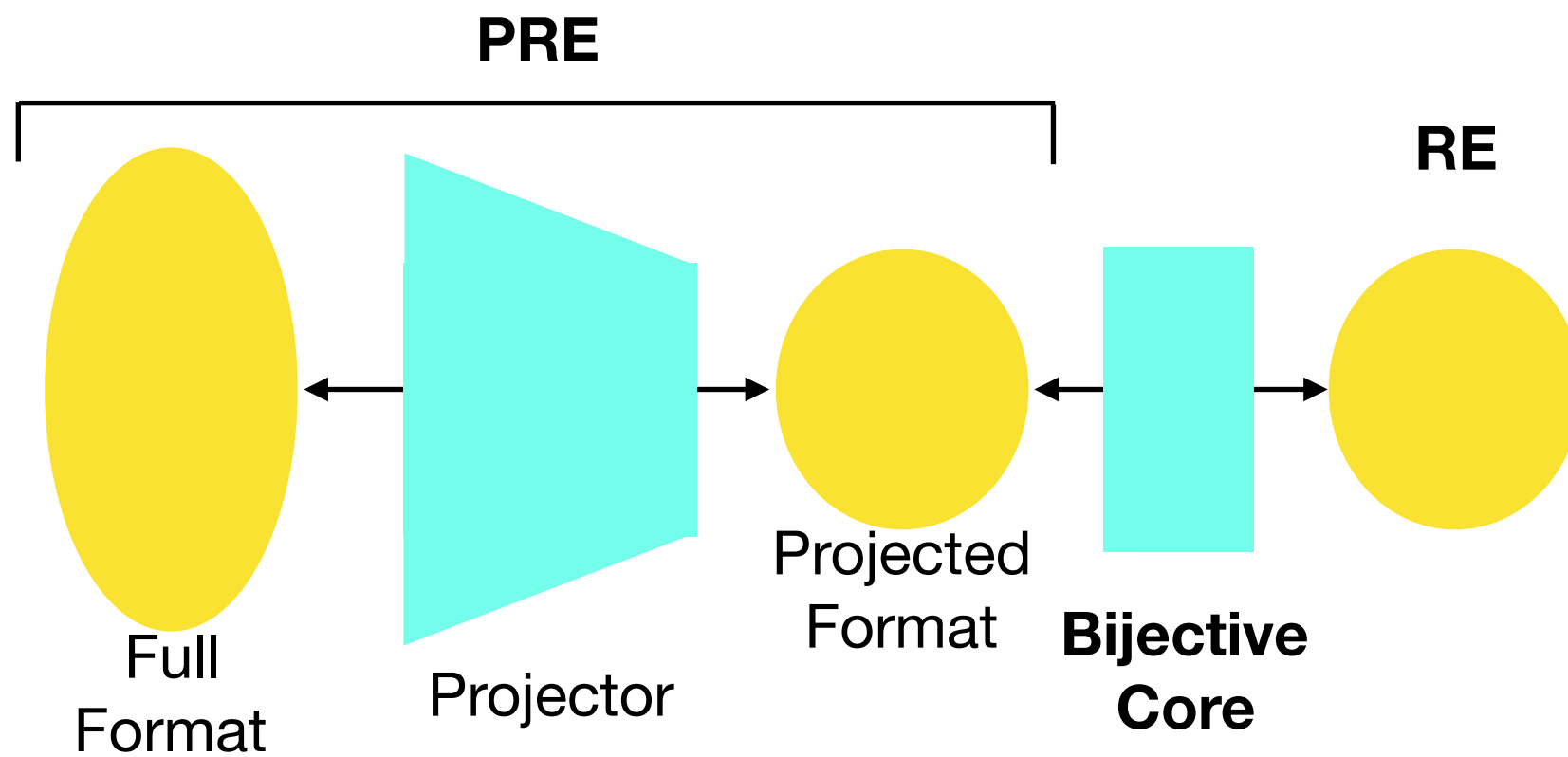


# Quotient Lens Synthesis

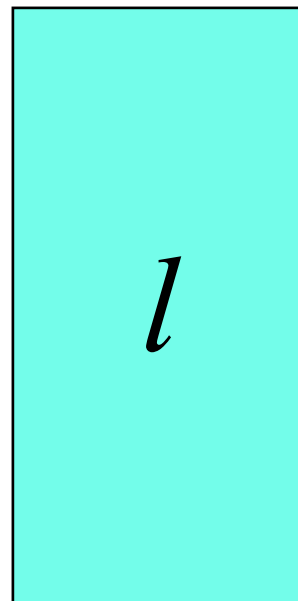
Sibelius, 1865



# Asymmetric Lens Synthesis



# Asymmetric Lenses



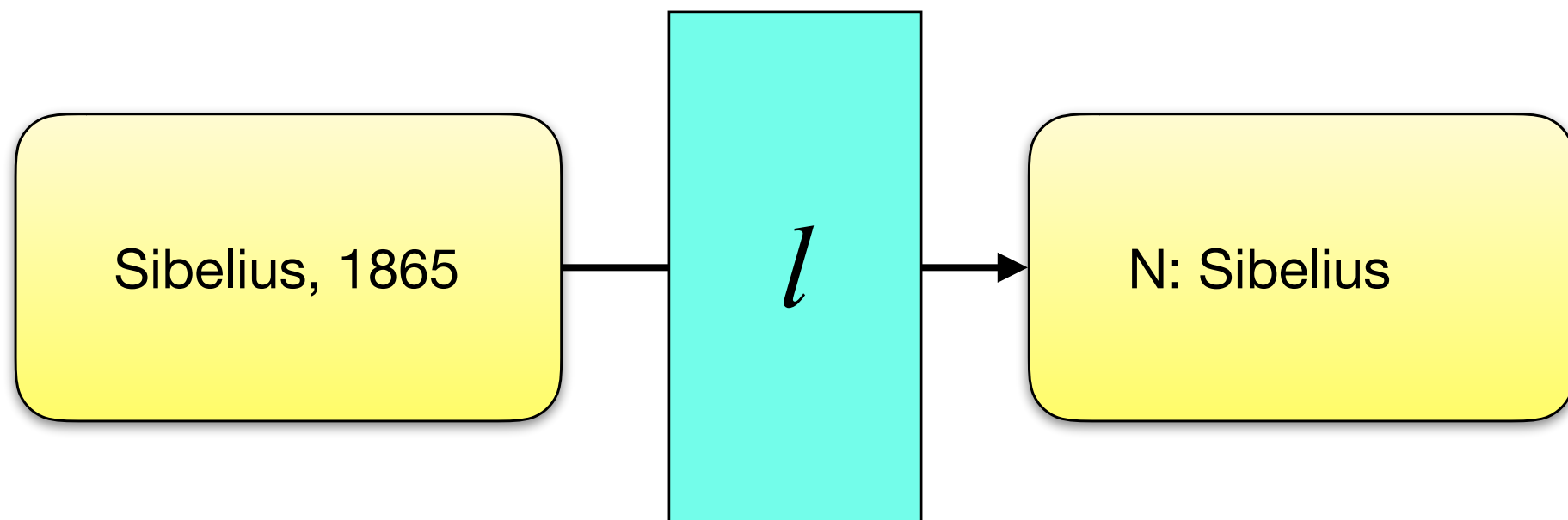
# Asymmetric Lenses

Sibelius, 1865

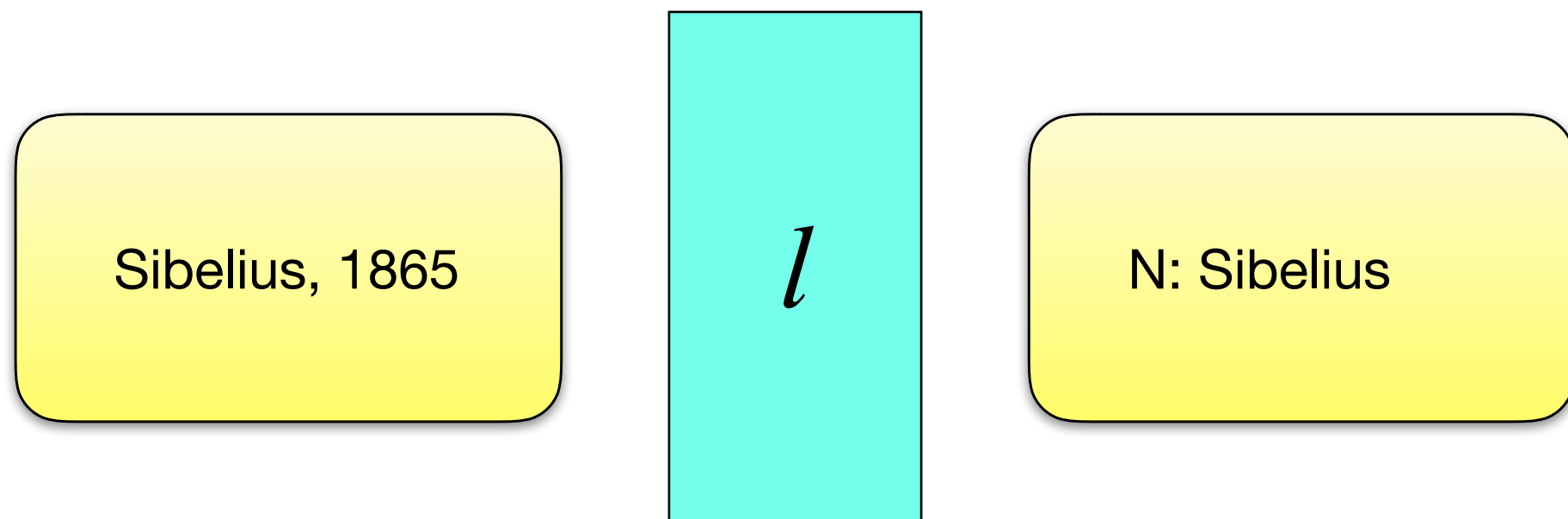
*l*



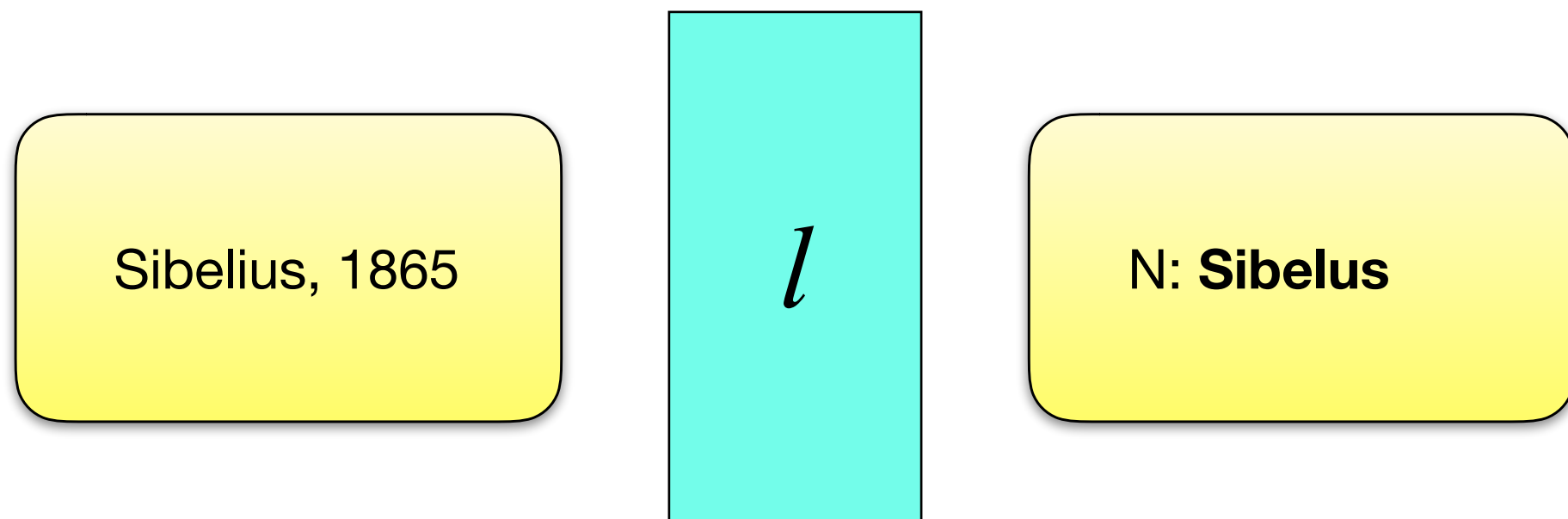
# Asymmetric Lenses



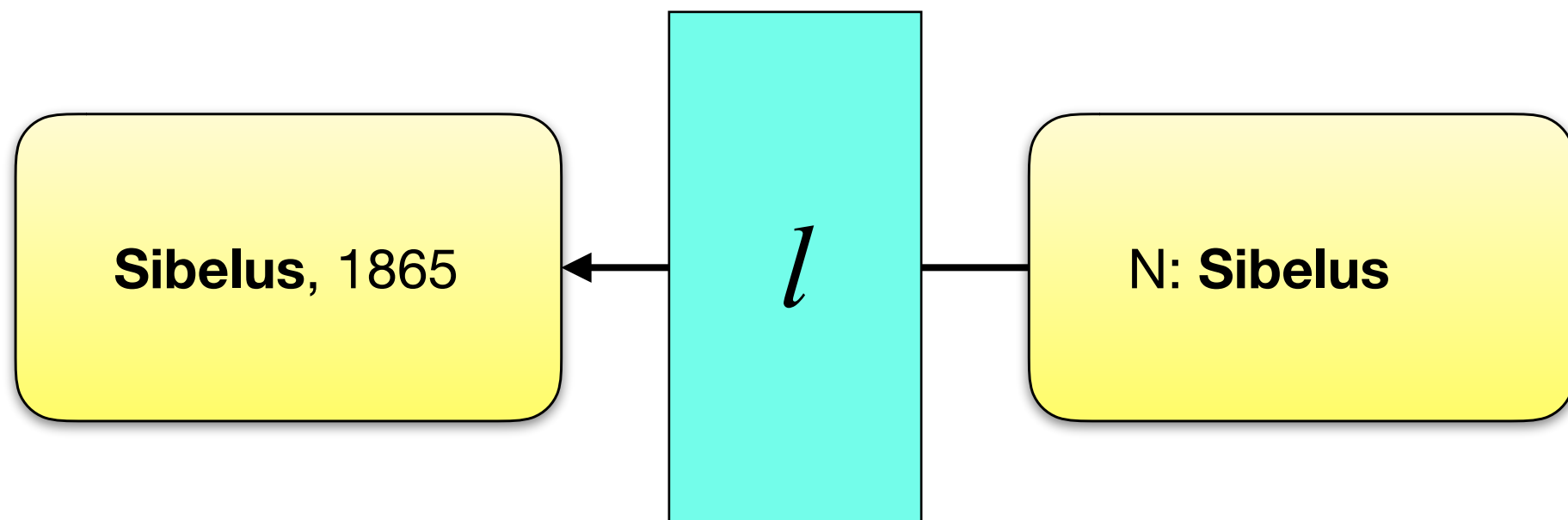
# Asymmetric Lenses



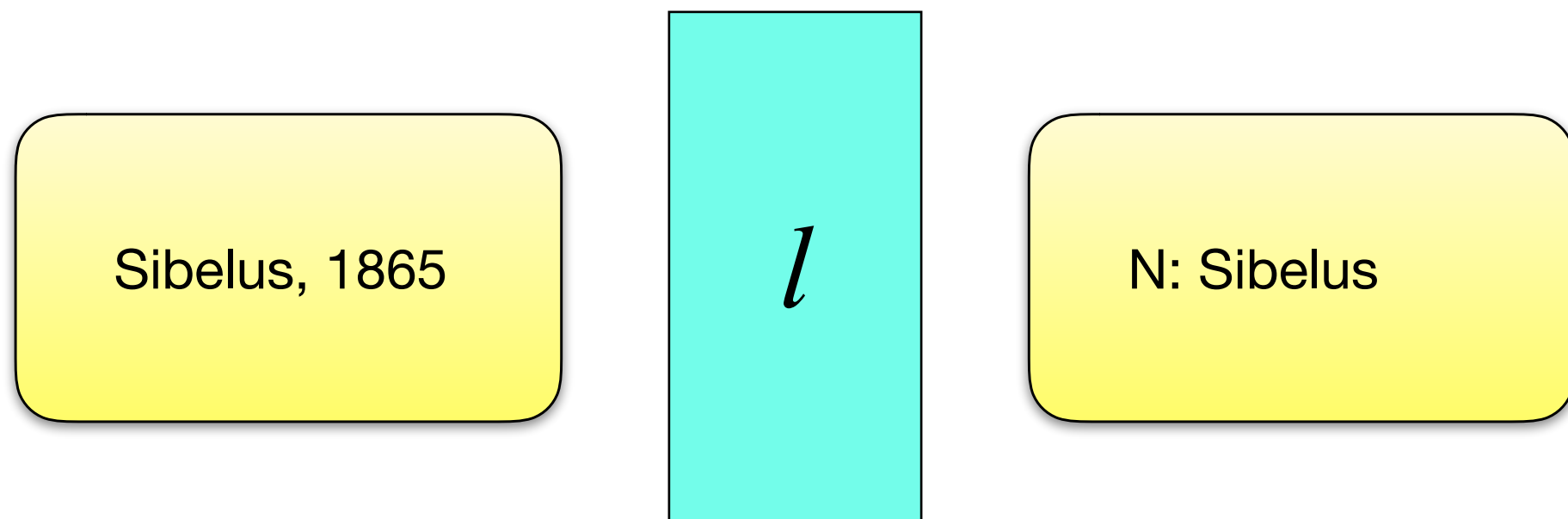
# Asymmetric Lenses



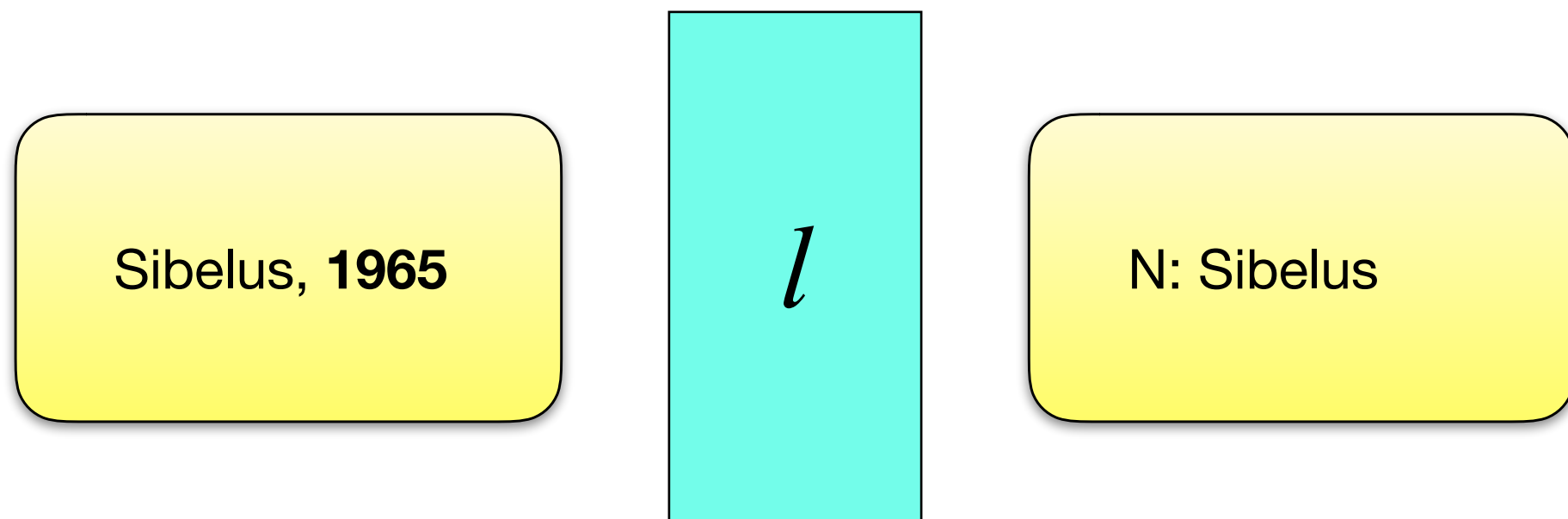
# Asymmetric Lenses



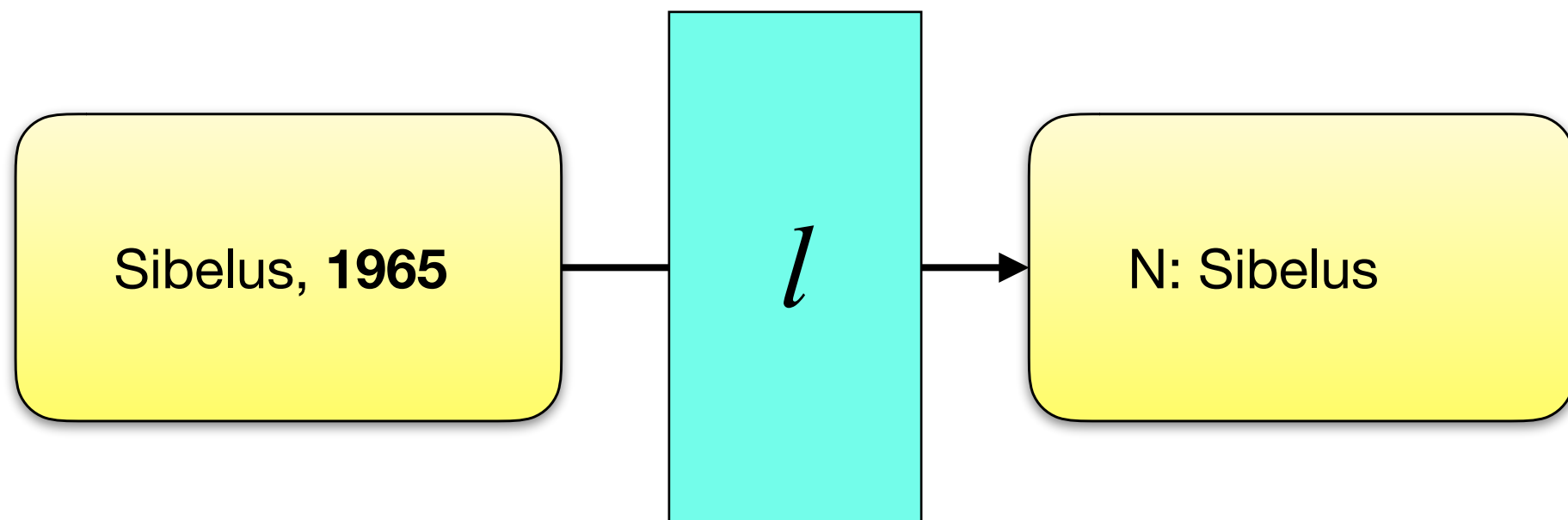
# Asymmetric Lenses



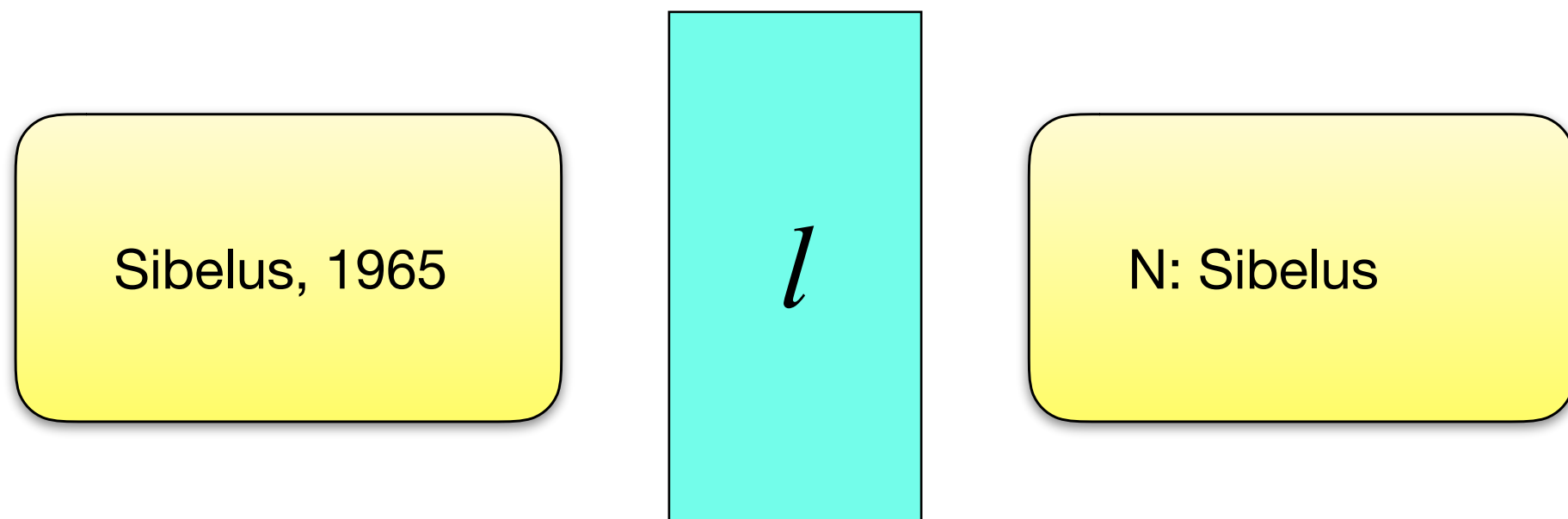
# Asymmetric Lenses



# Asymmetric Lenses

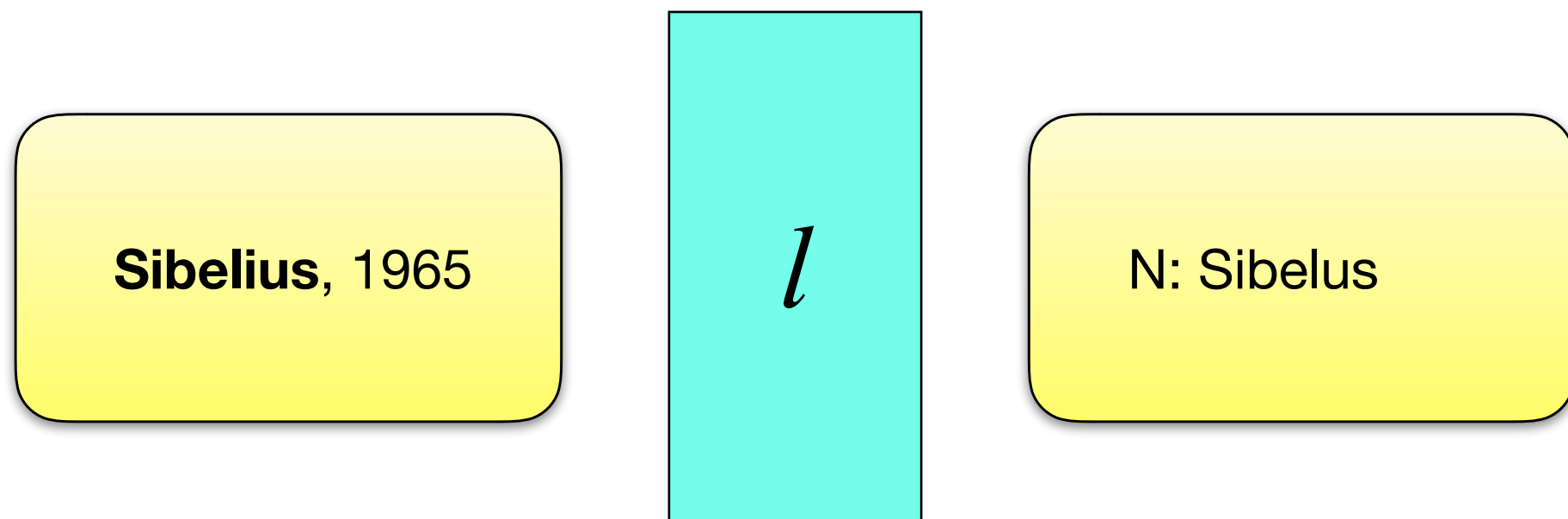


# Asymmetric Lenses

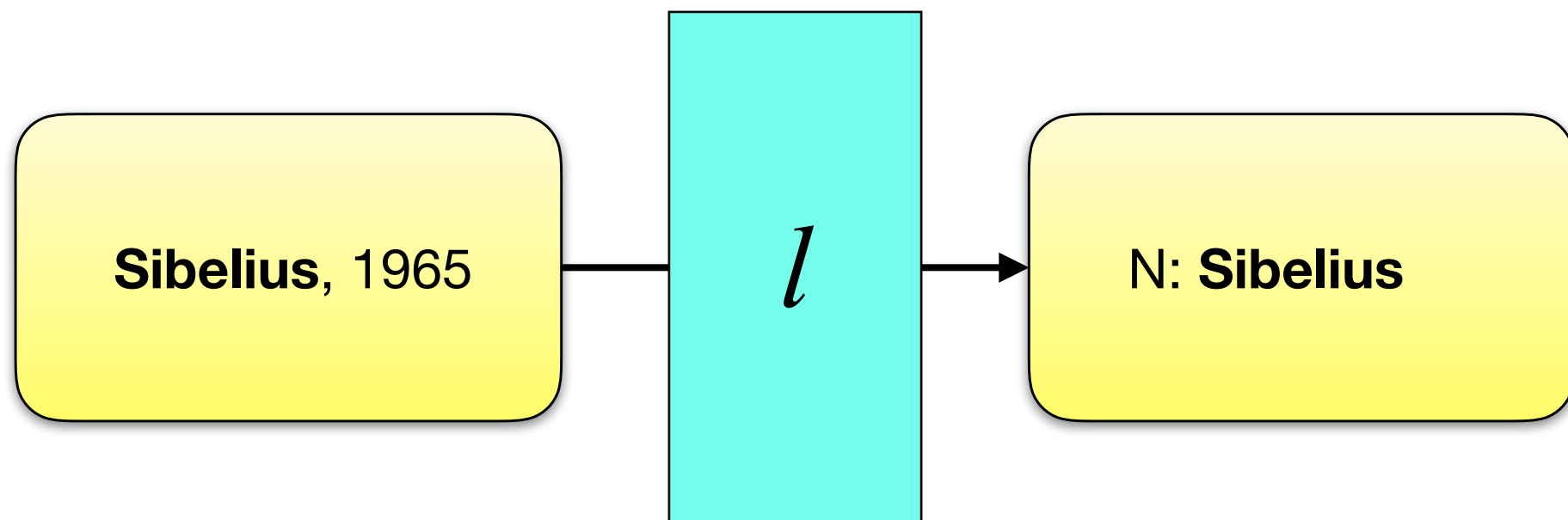




# Asymmetric Lenses

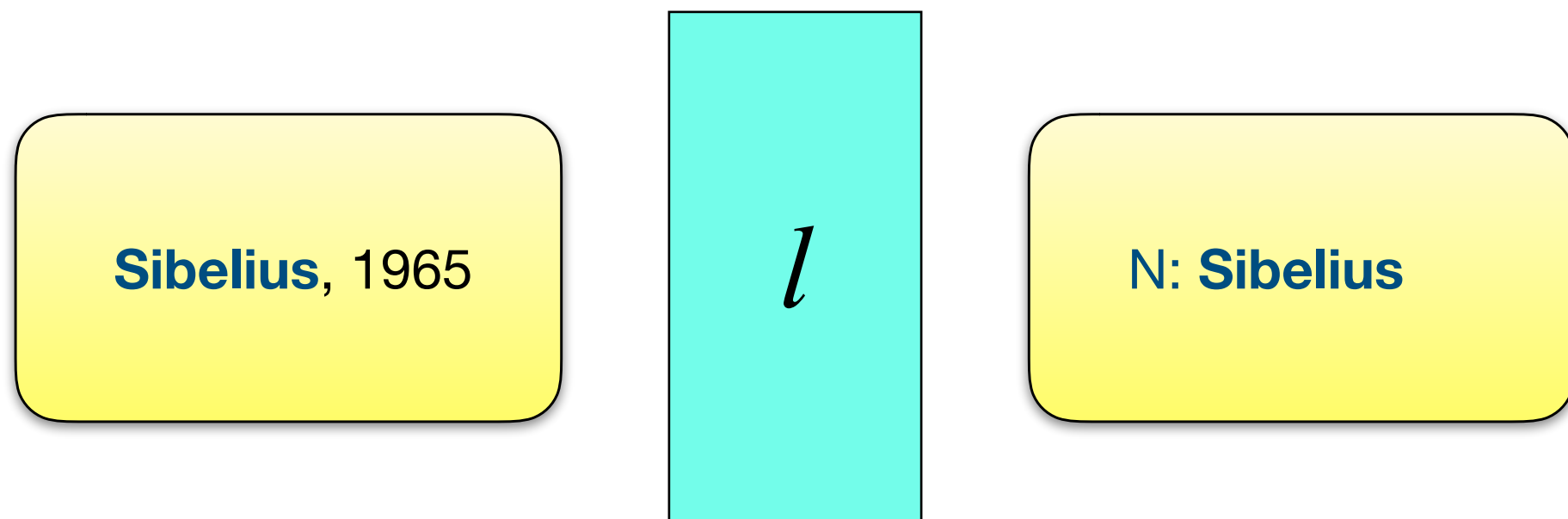


# Asymmetric Lenses

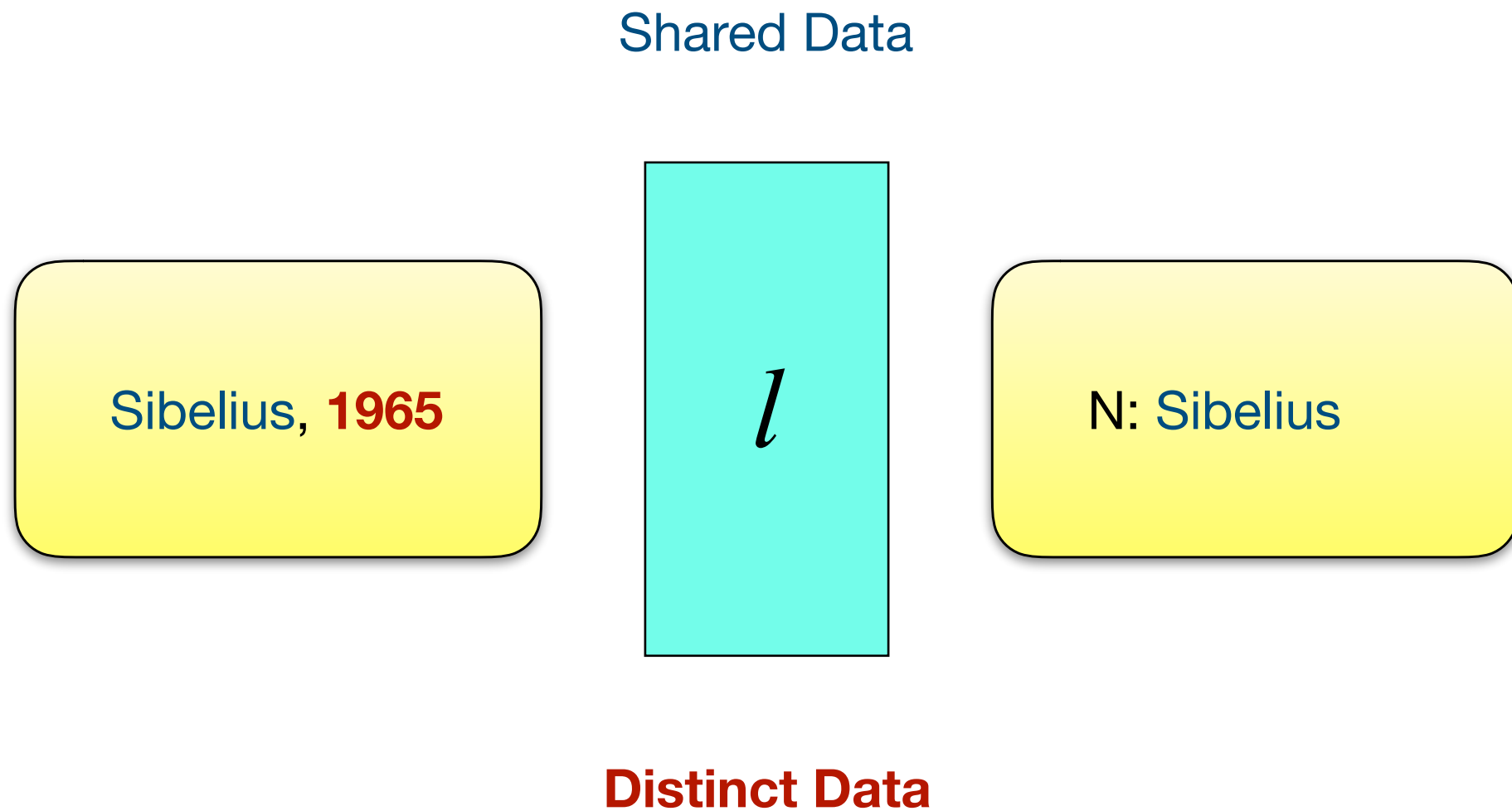


# Asymmetric Lenses

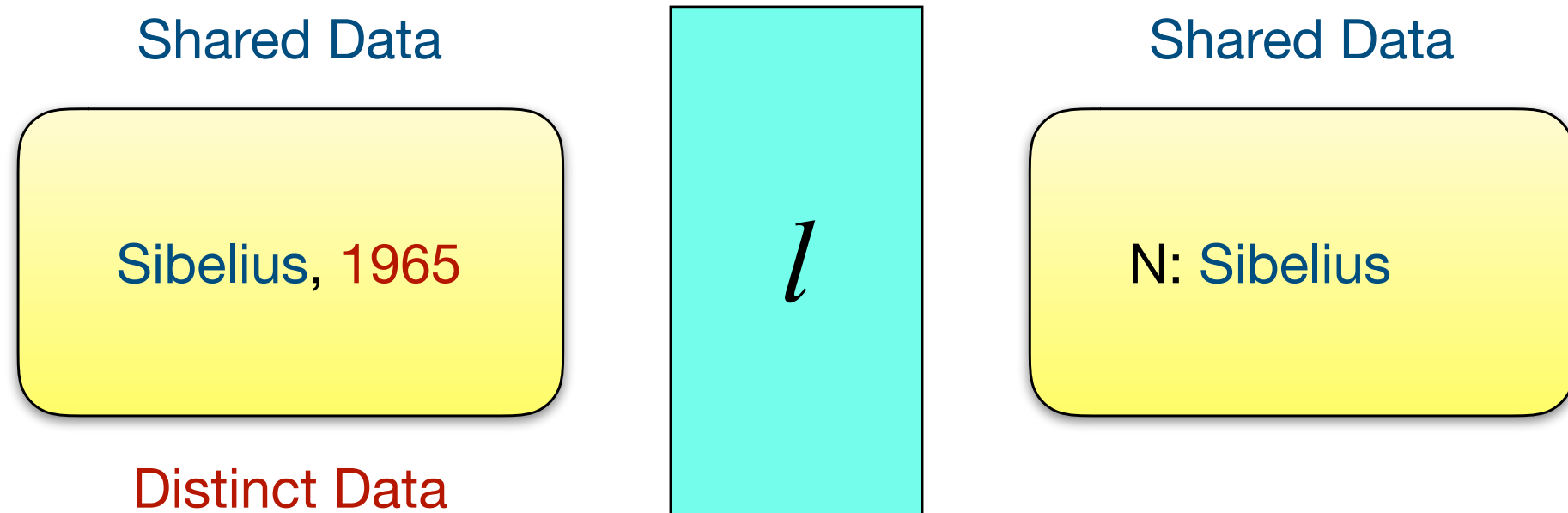
Shared Data



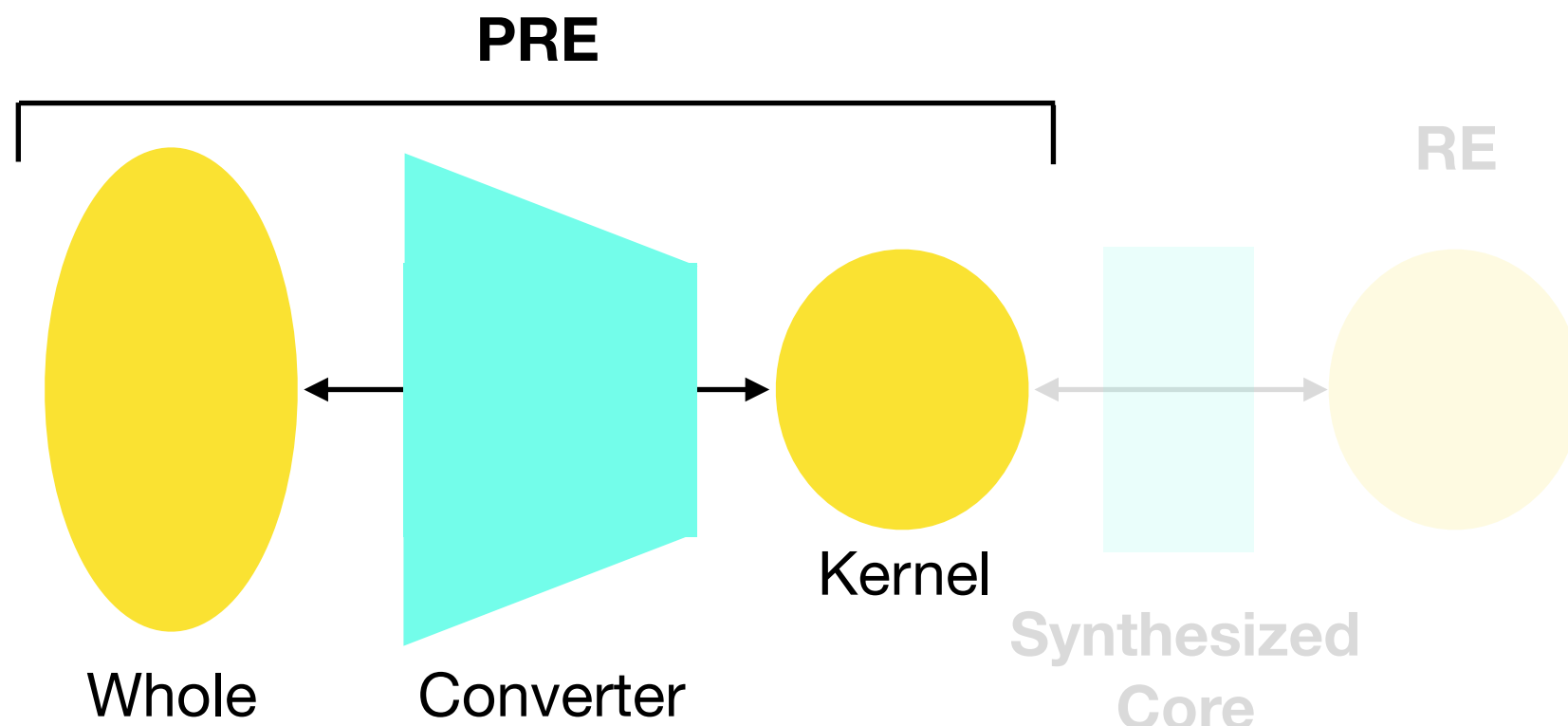
# Asymmetric Lenses



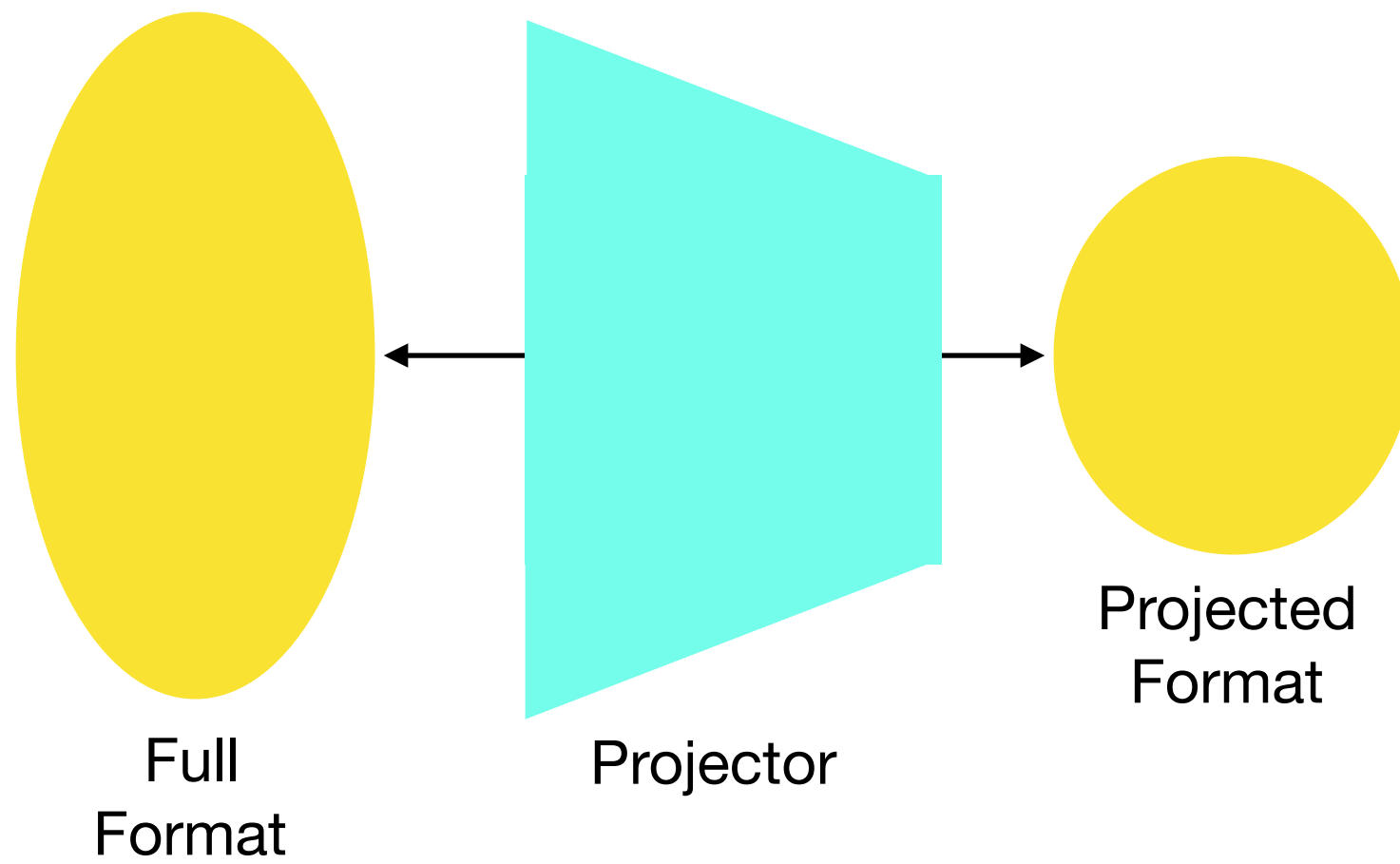
# Asymmetric Lenses



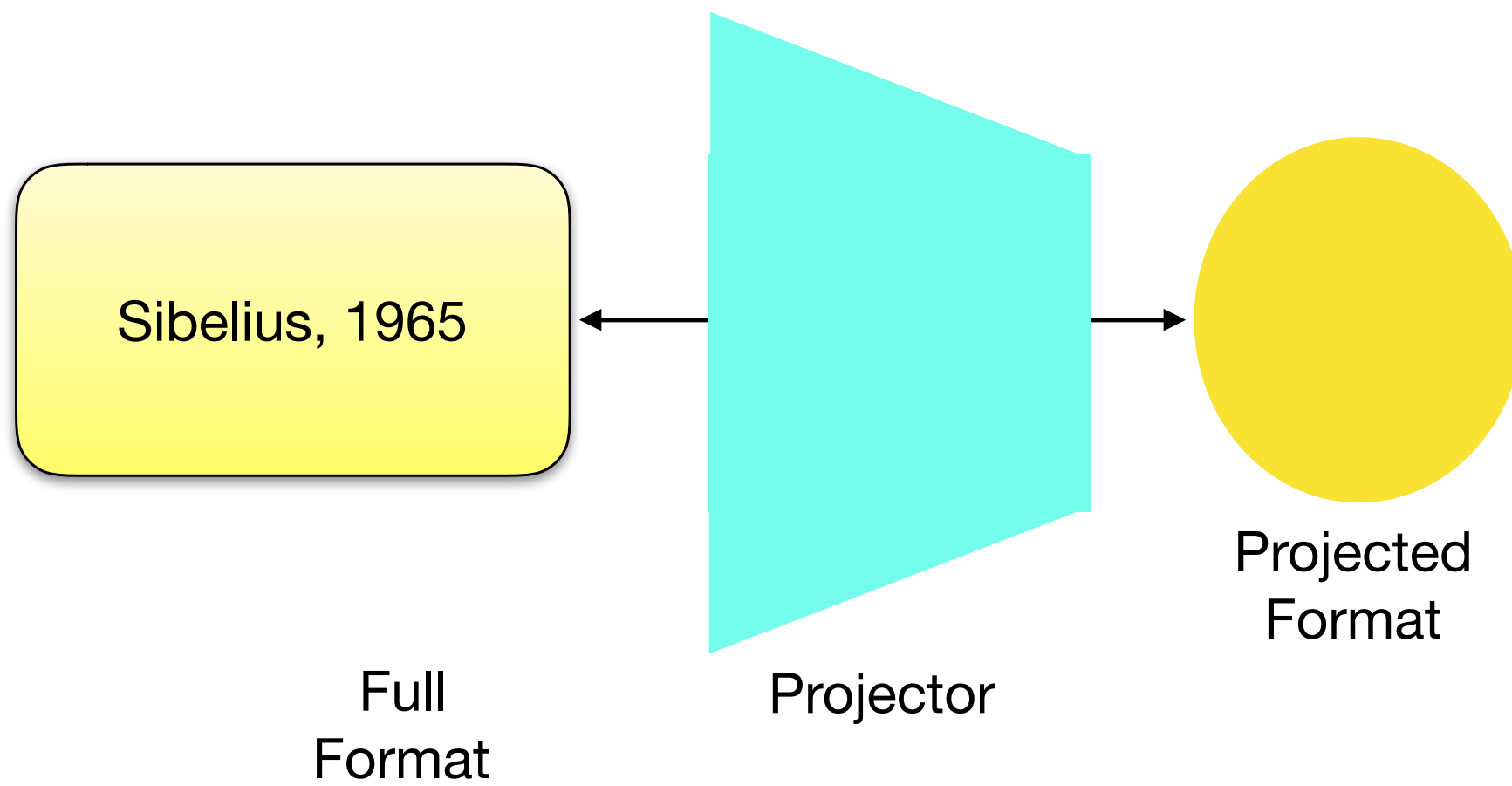
# Asymmetric Lens Synthesis



# PRE

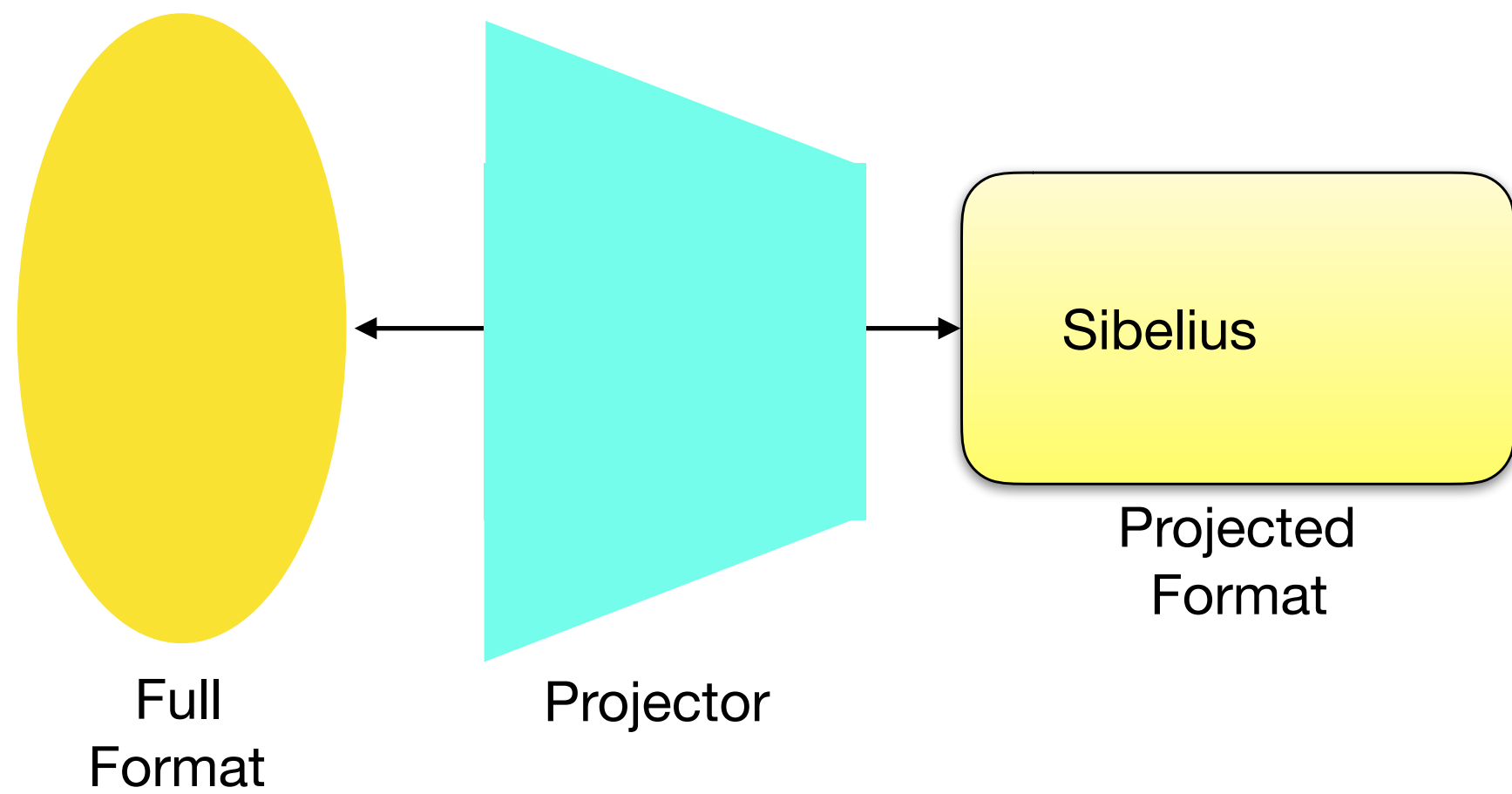


# PRE

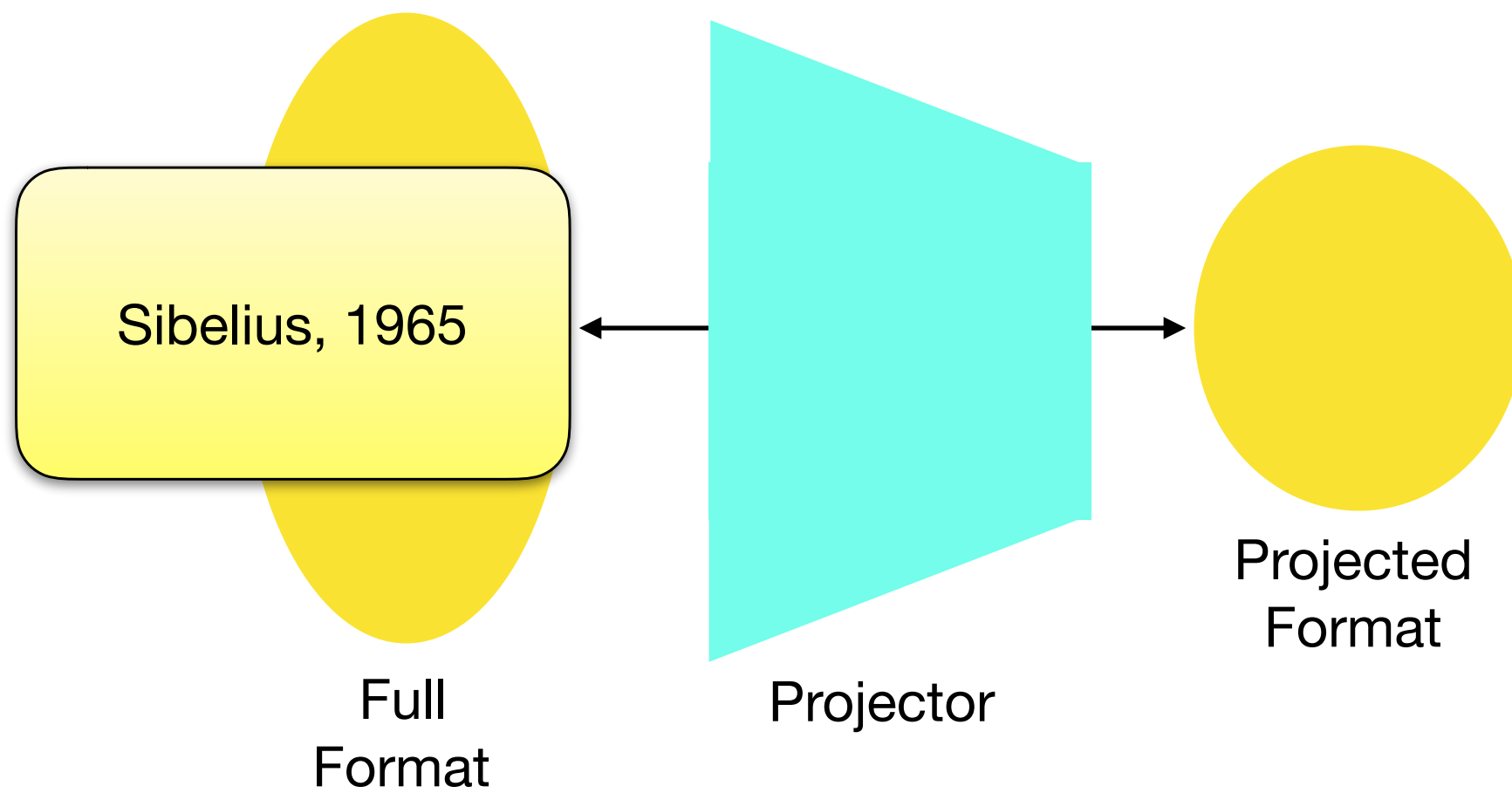




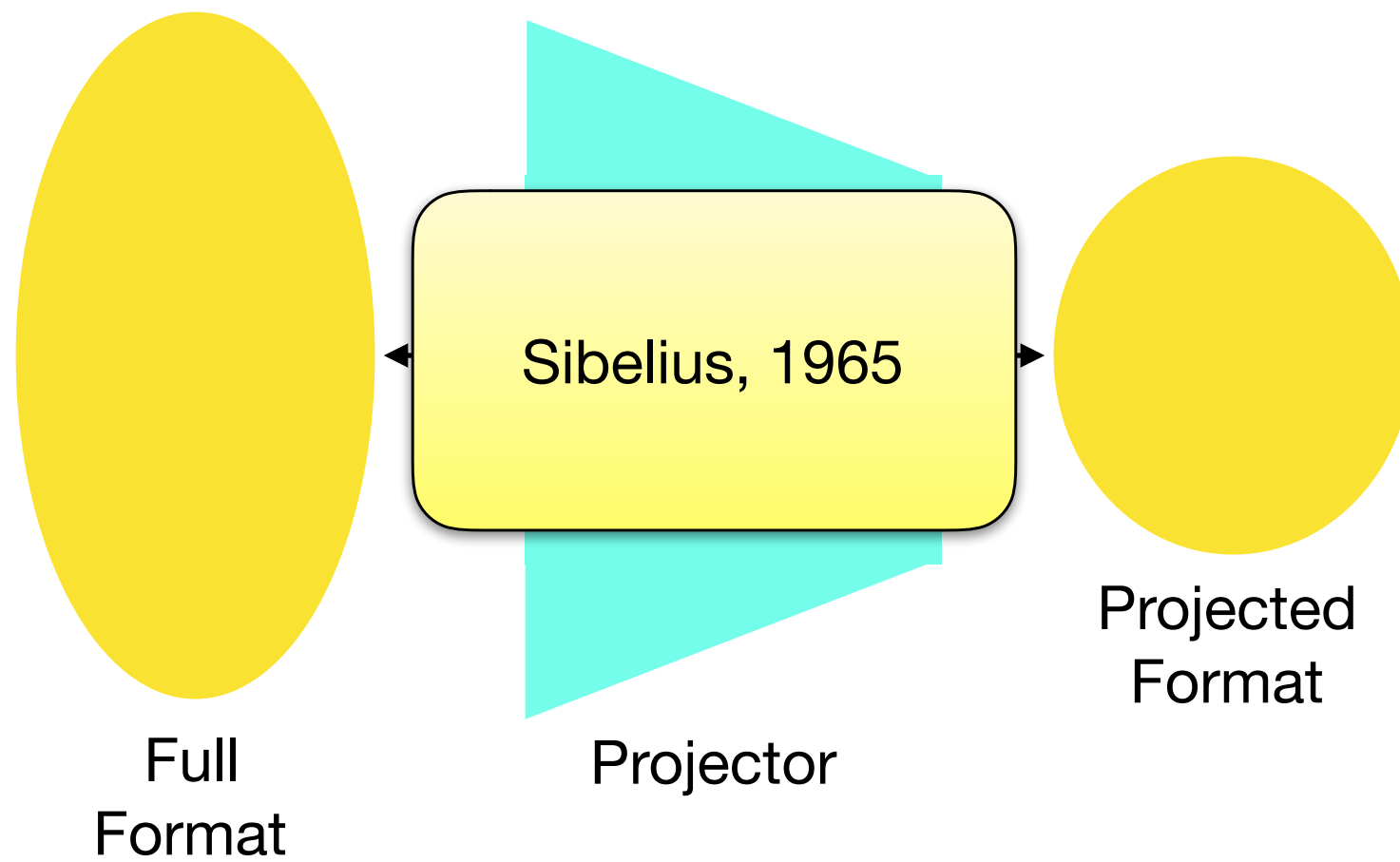
# PRE



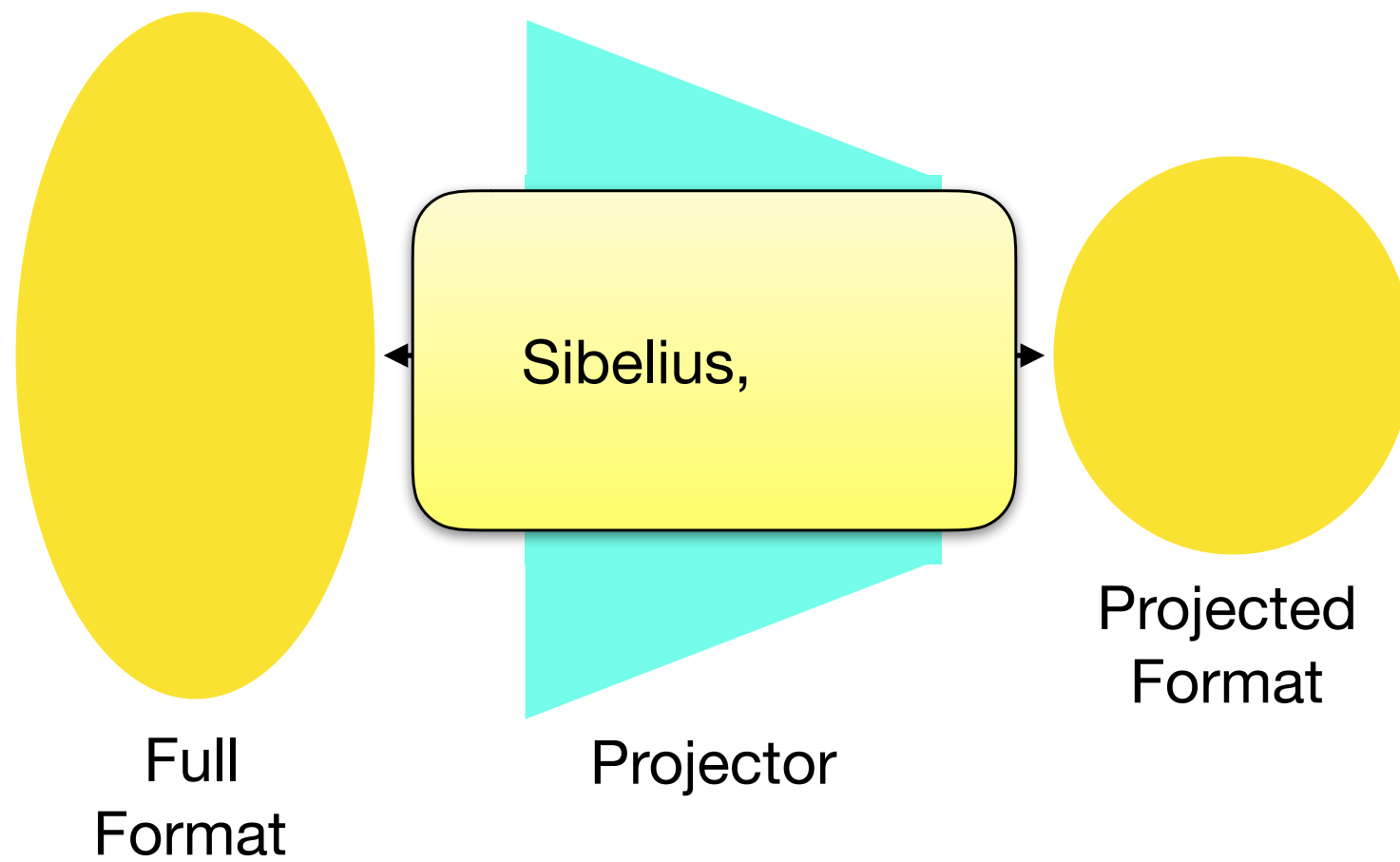
# PRE



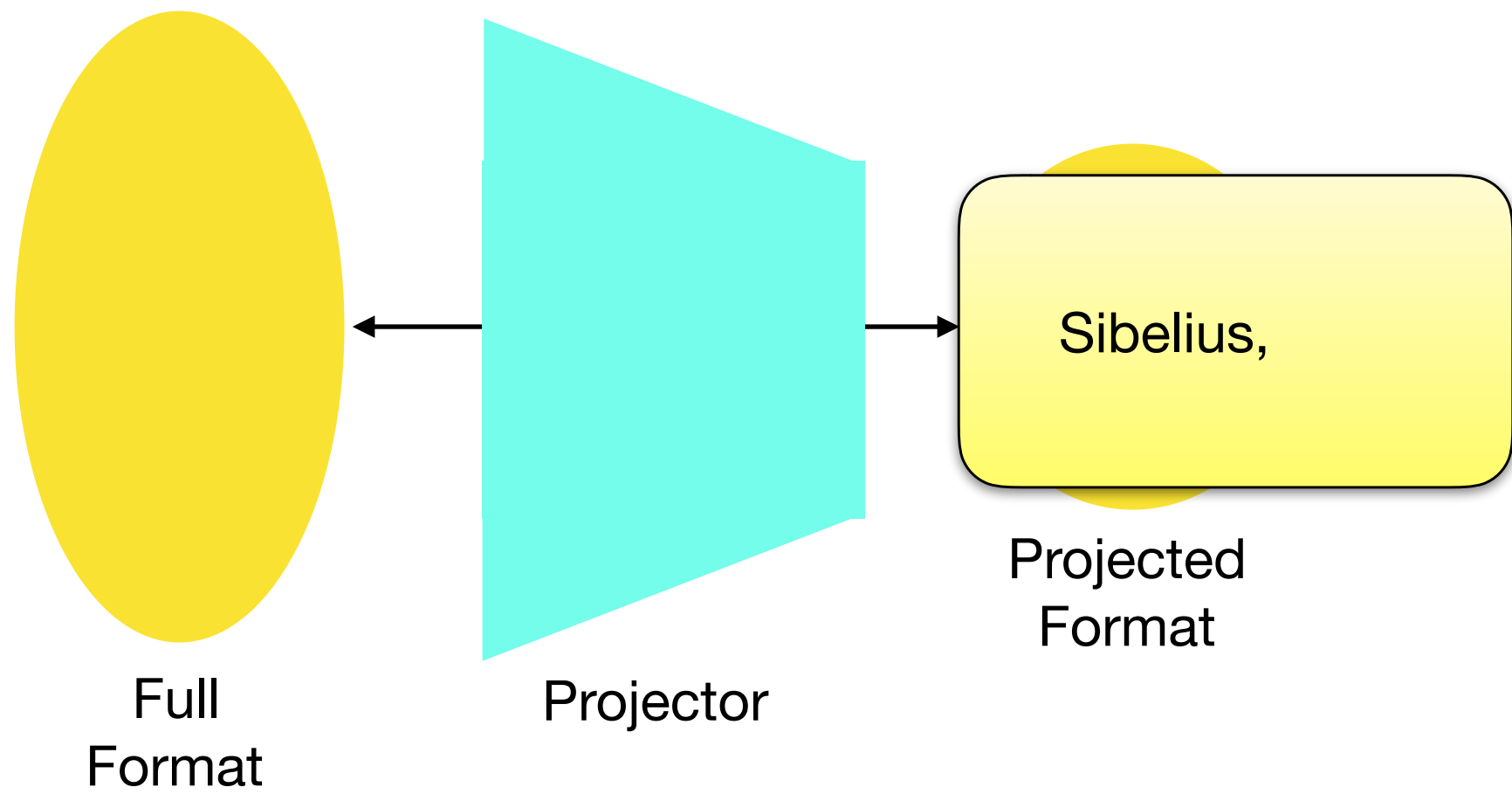
# PRE



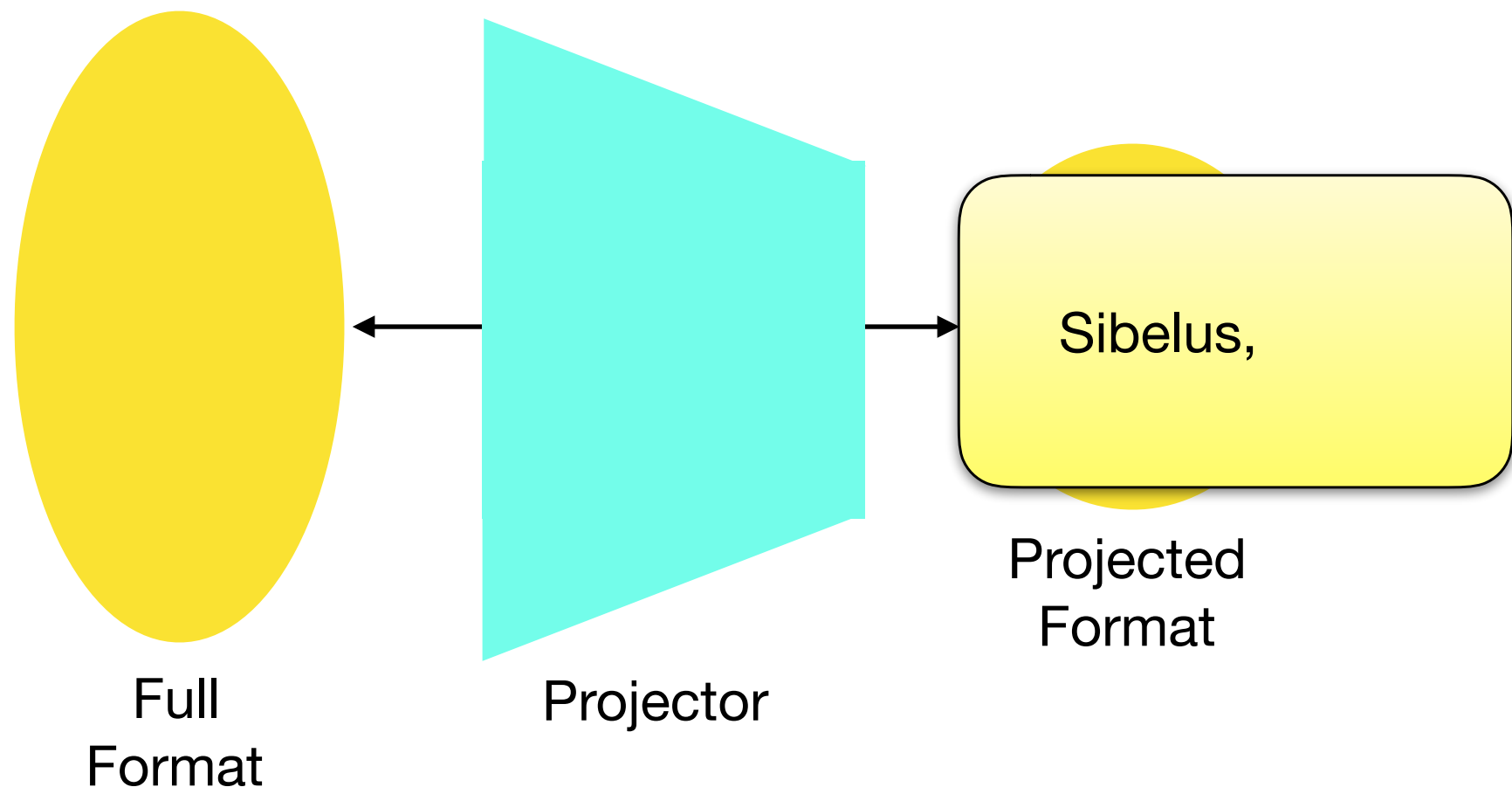
# PRE



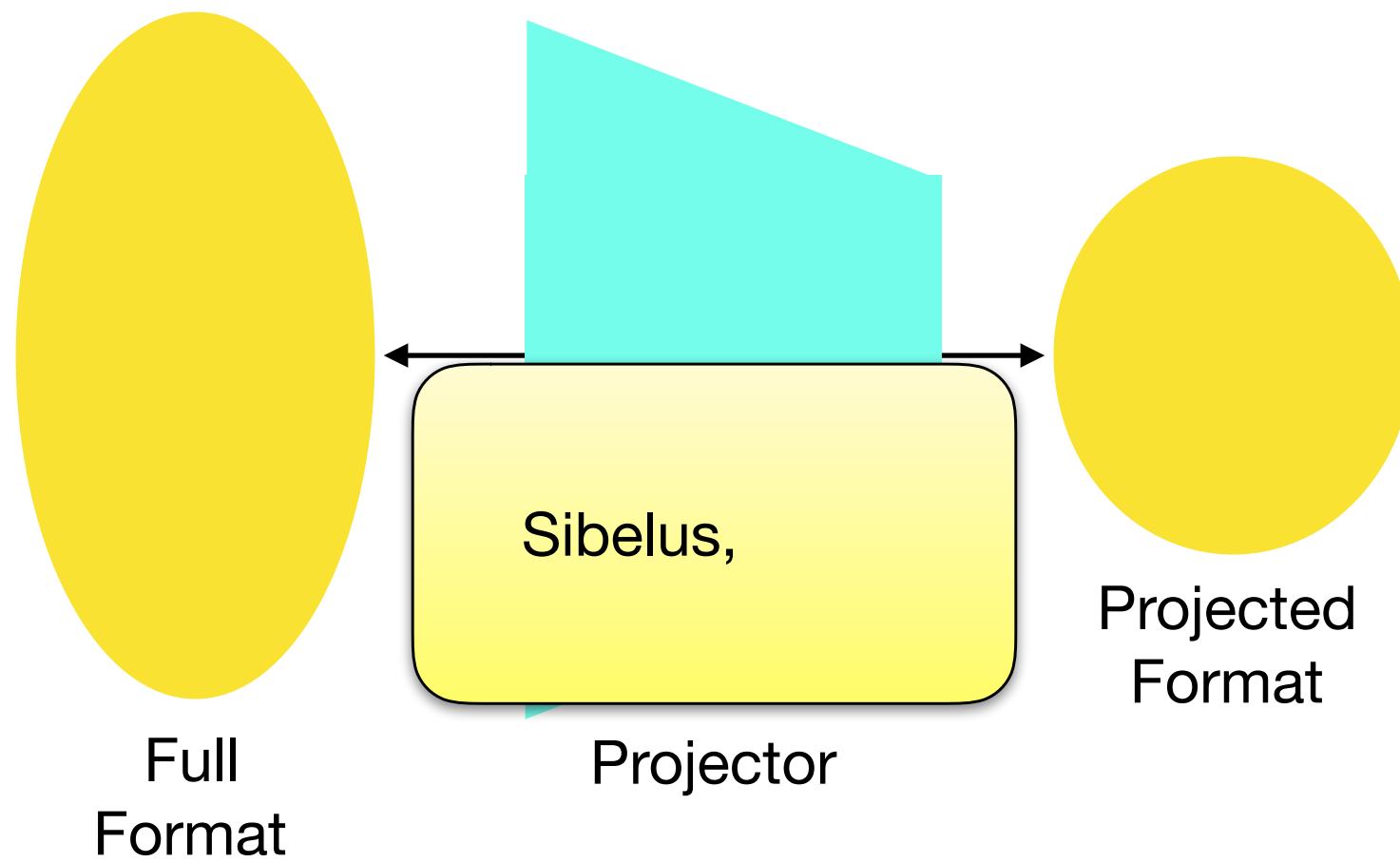
# PRE



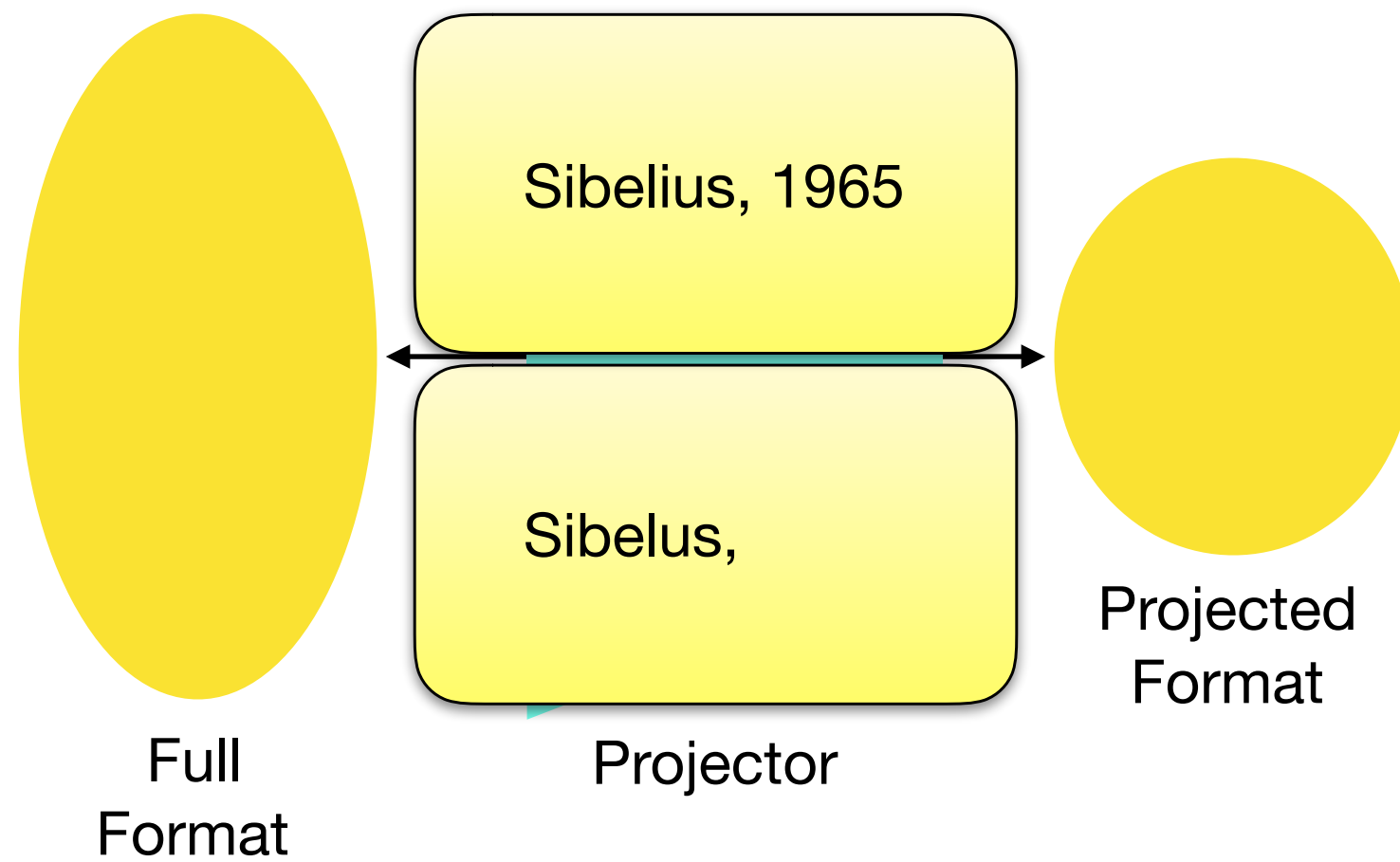
# PRE



# PRE

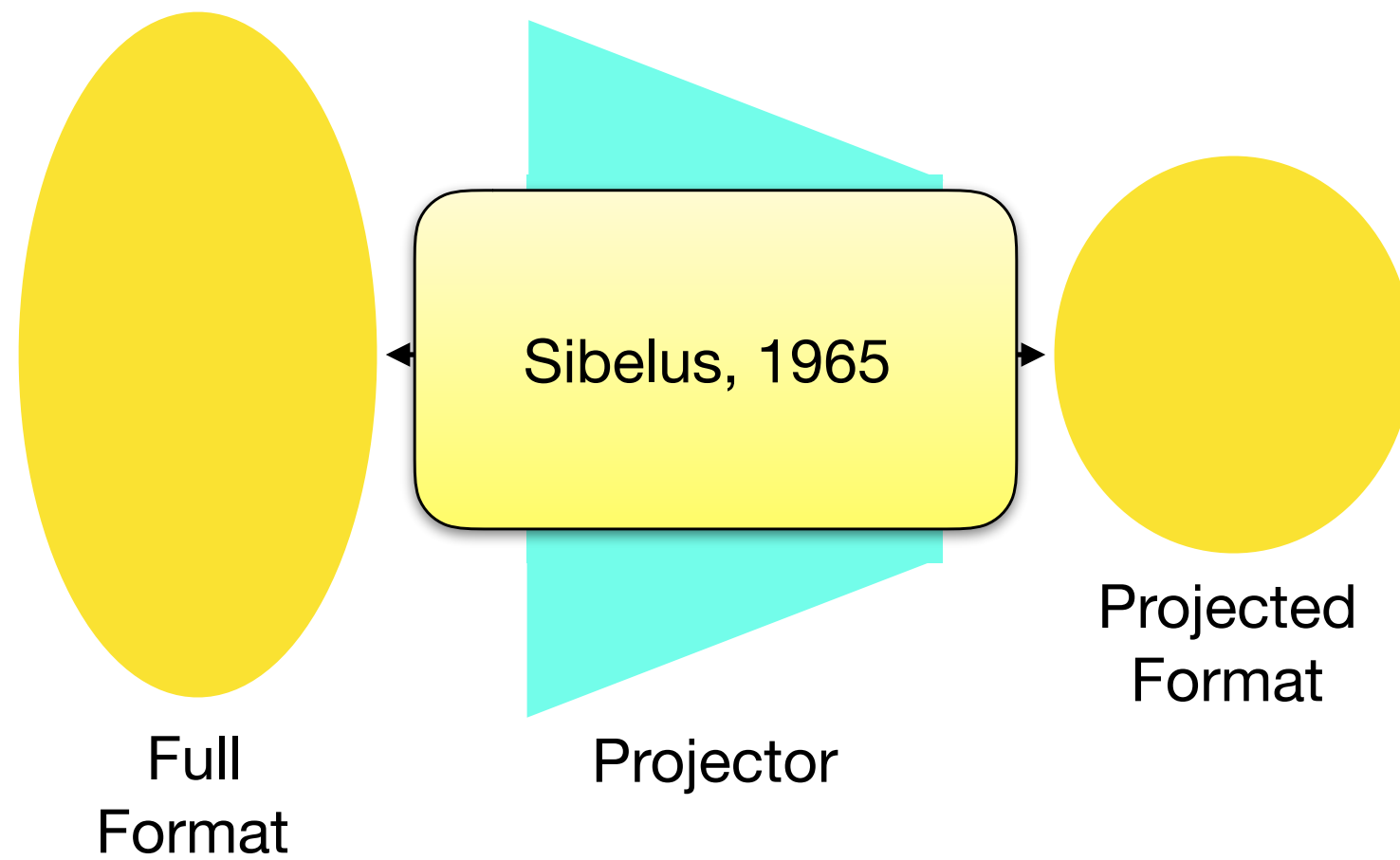


# PRE

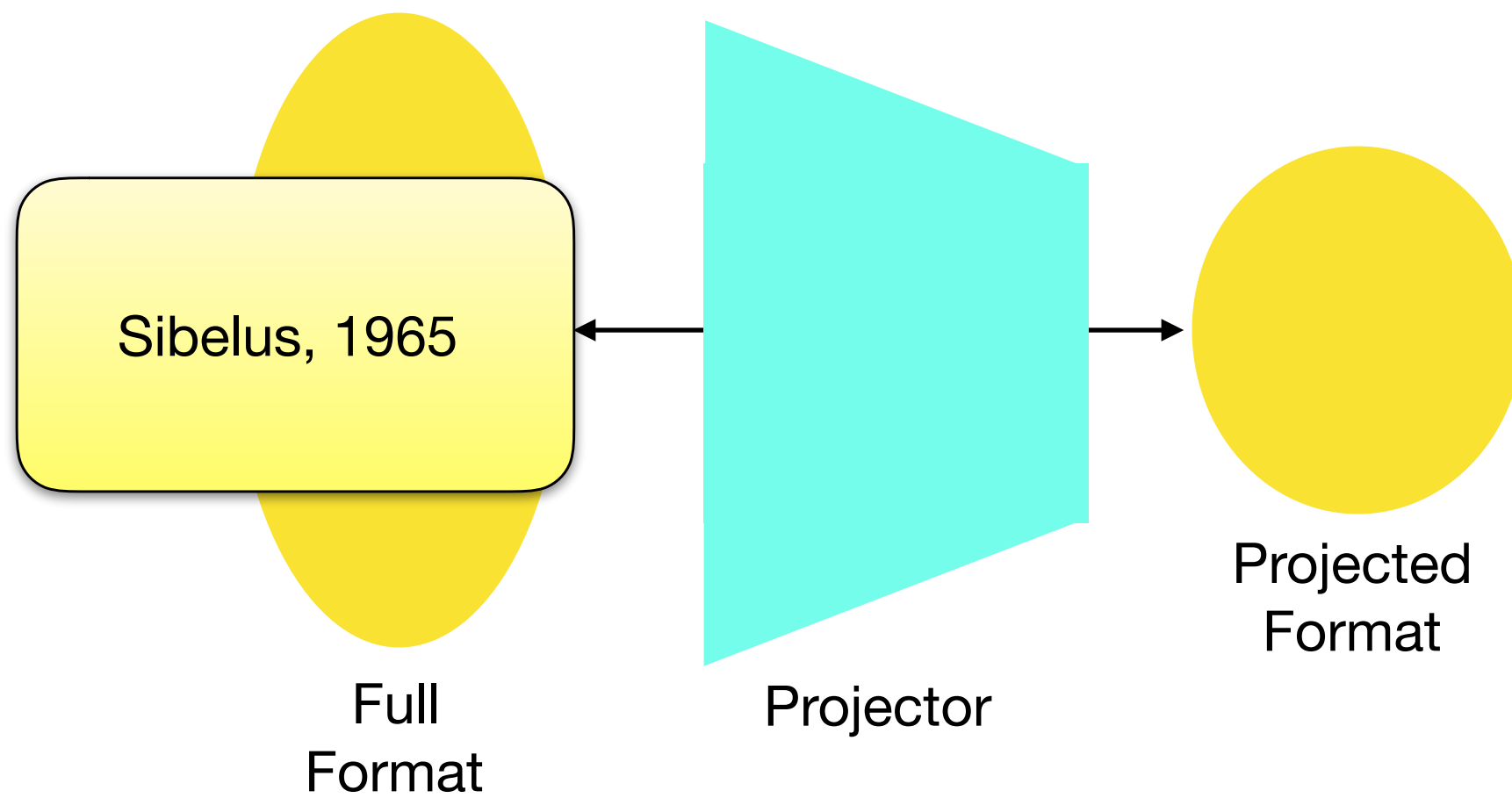




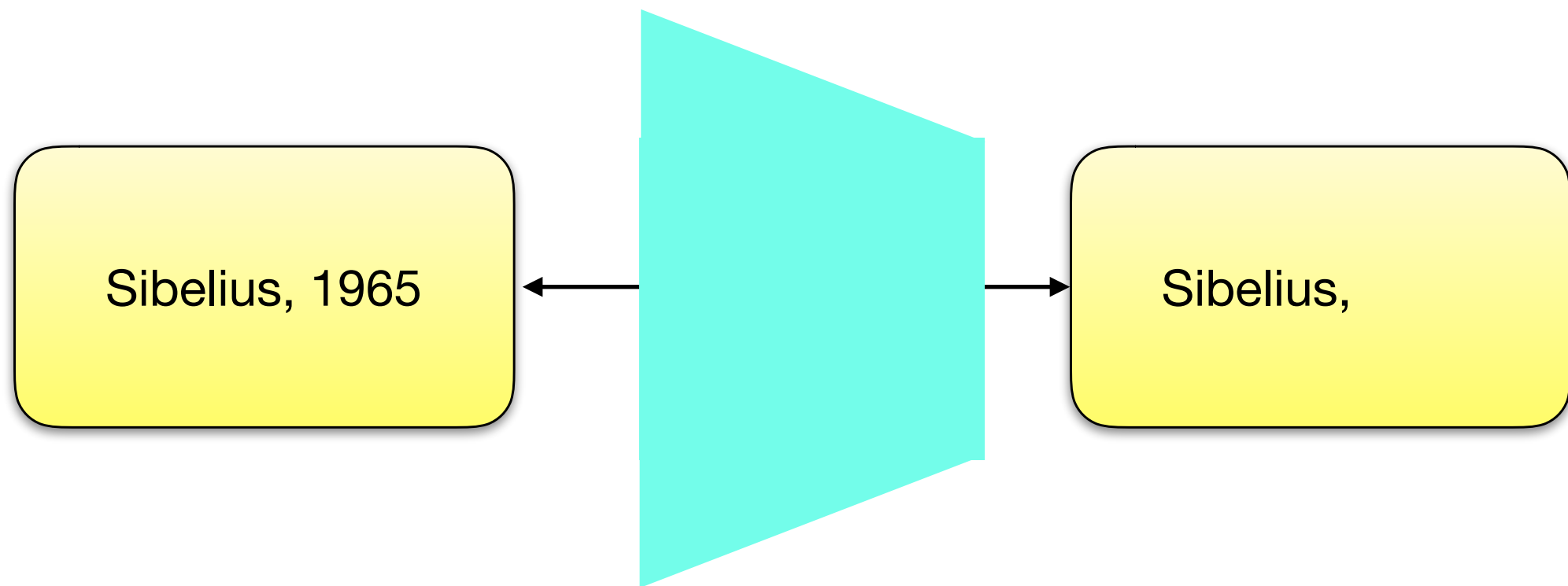
# PRE



# PRE

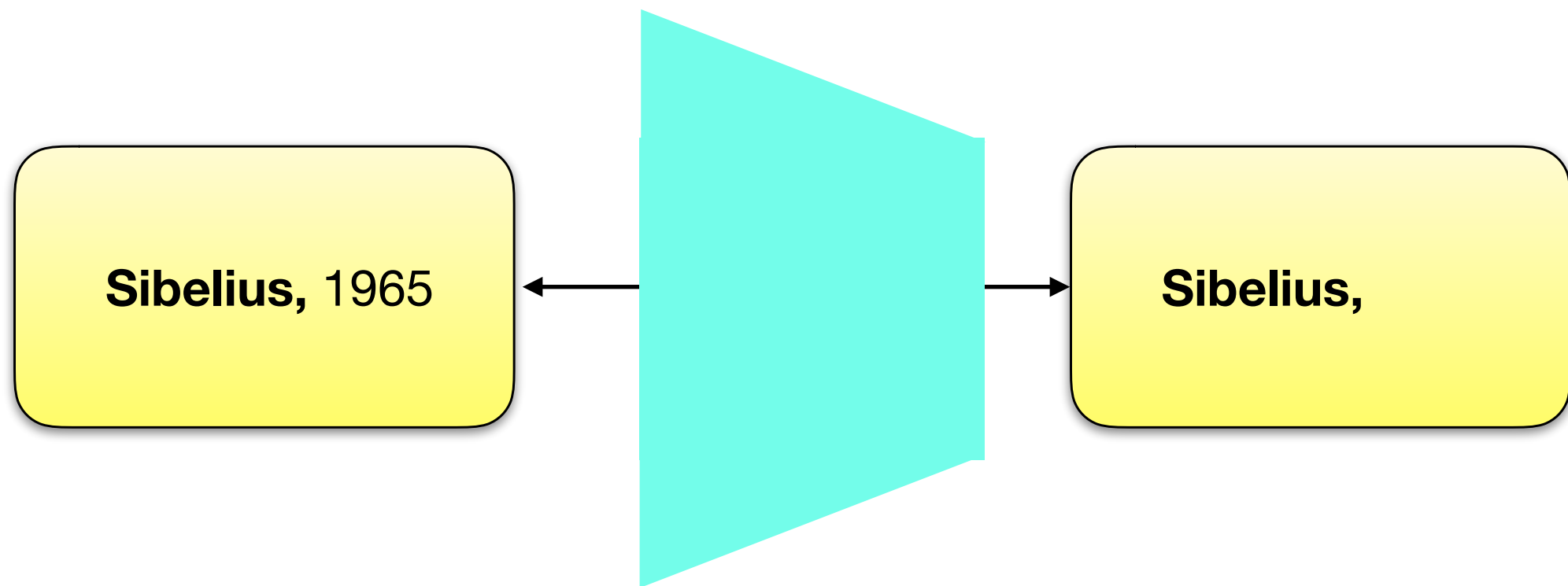


# PRE



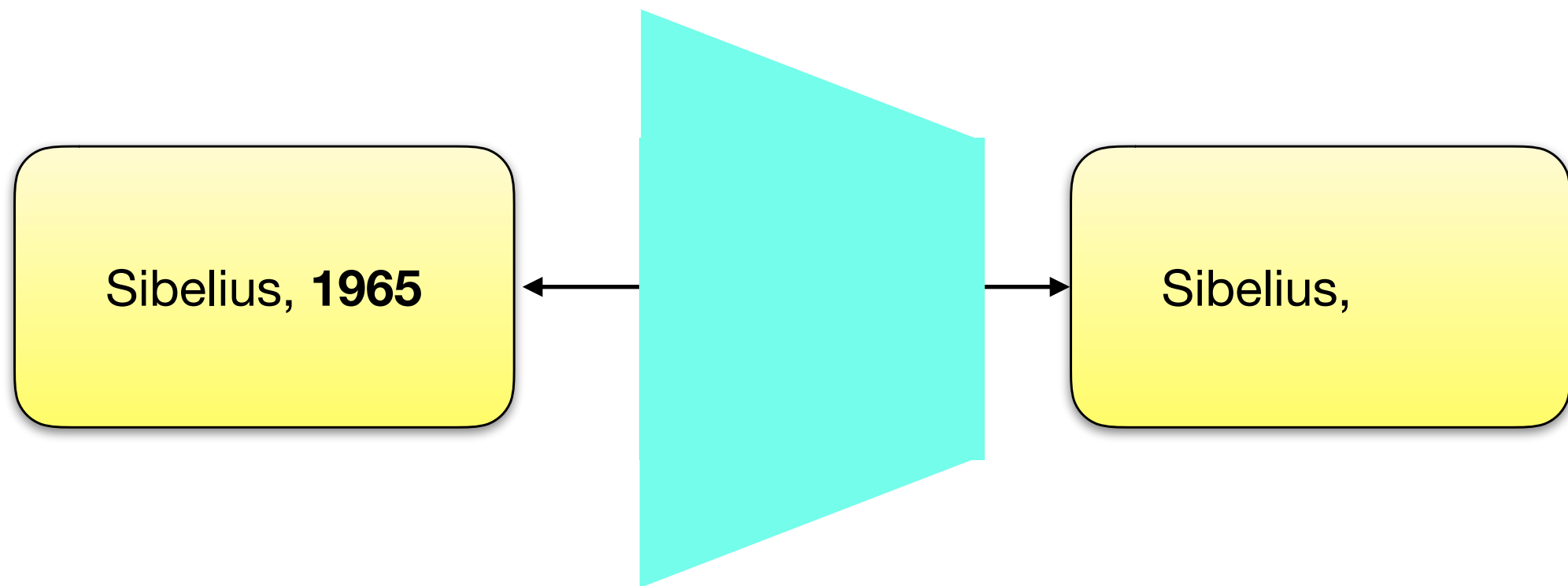
```
Name . " , "  
      . skip(Date)
```

# PRE



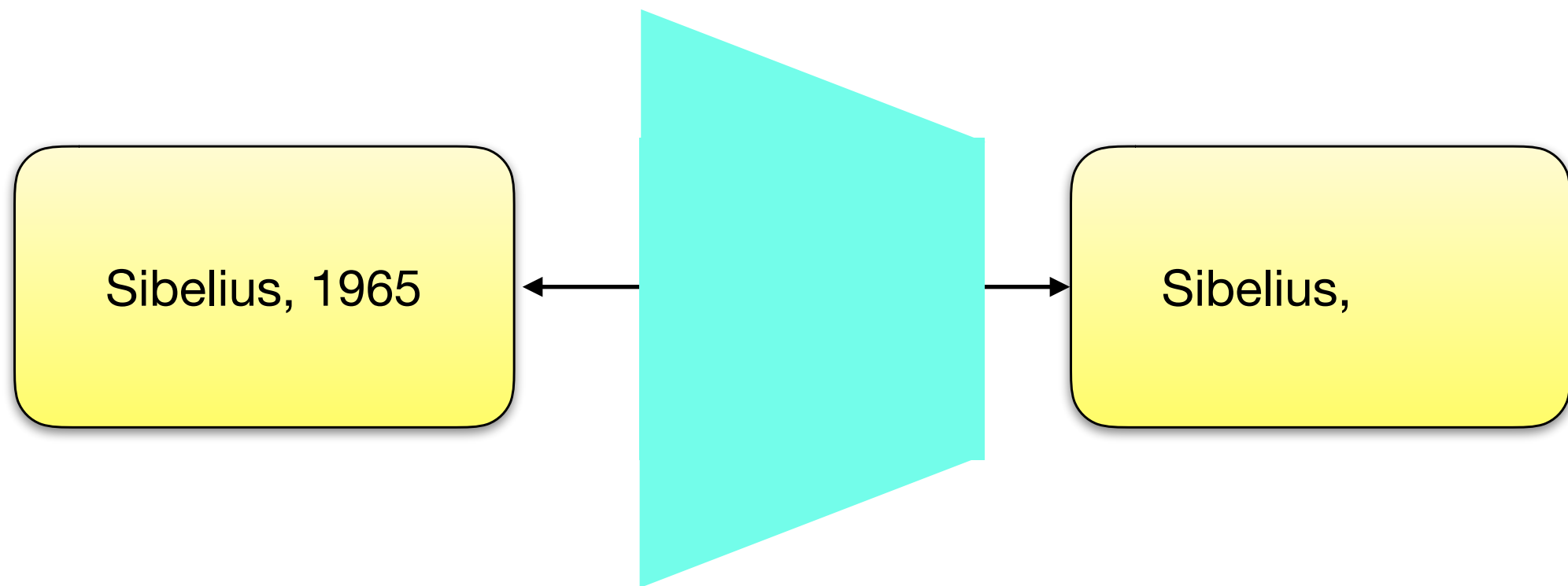
```
Name . " , "  
      . skip(Date)
```

# PRE



```
Name . " , "  
      . skip(Date)
```

# PRE

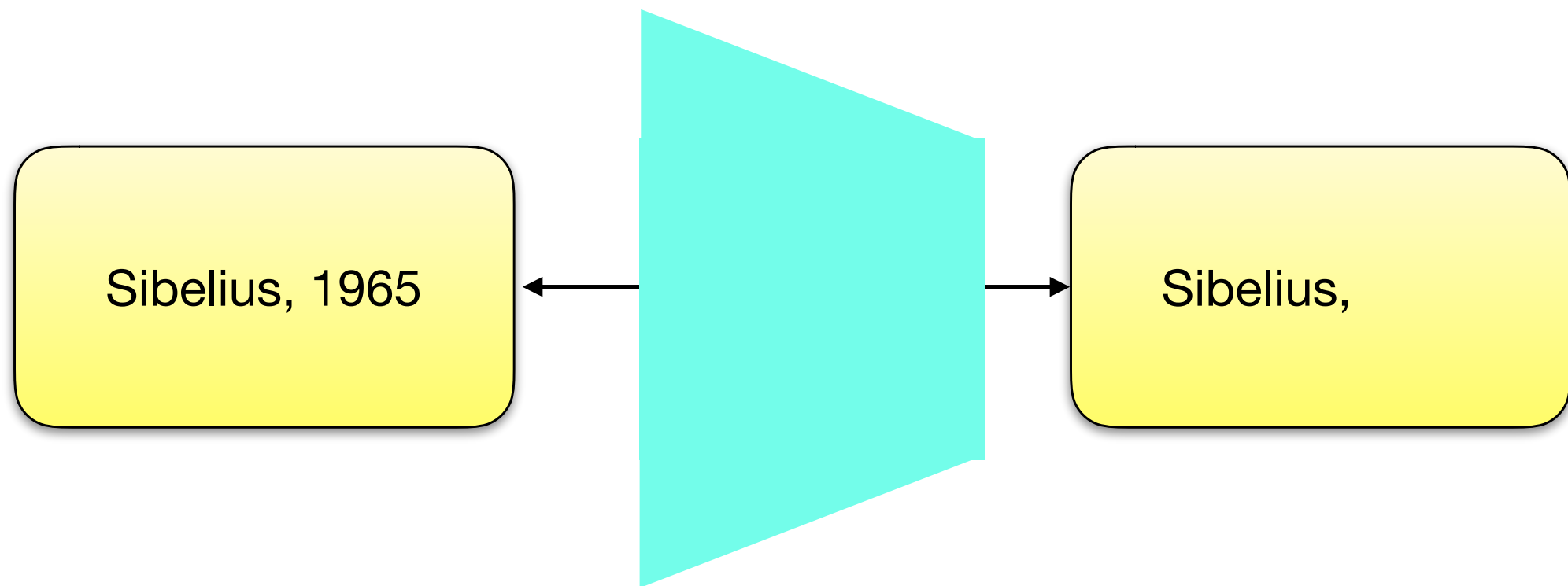


Name . " , "  
 . skip(Date)

# PRE

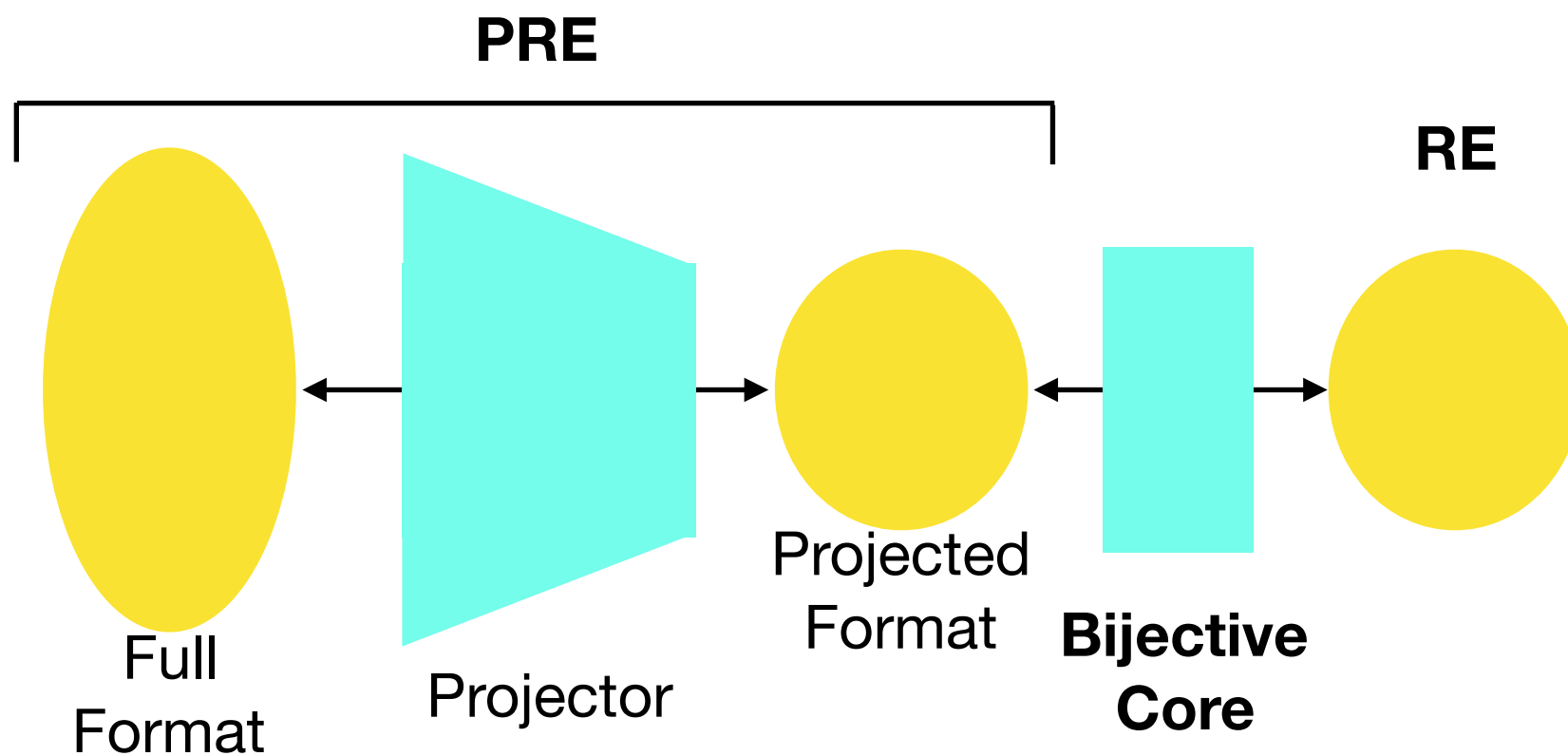
Name . “ , “  
 . Date

Name . “ , “

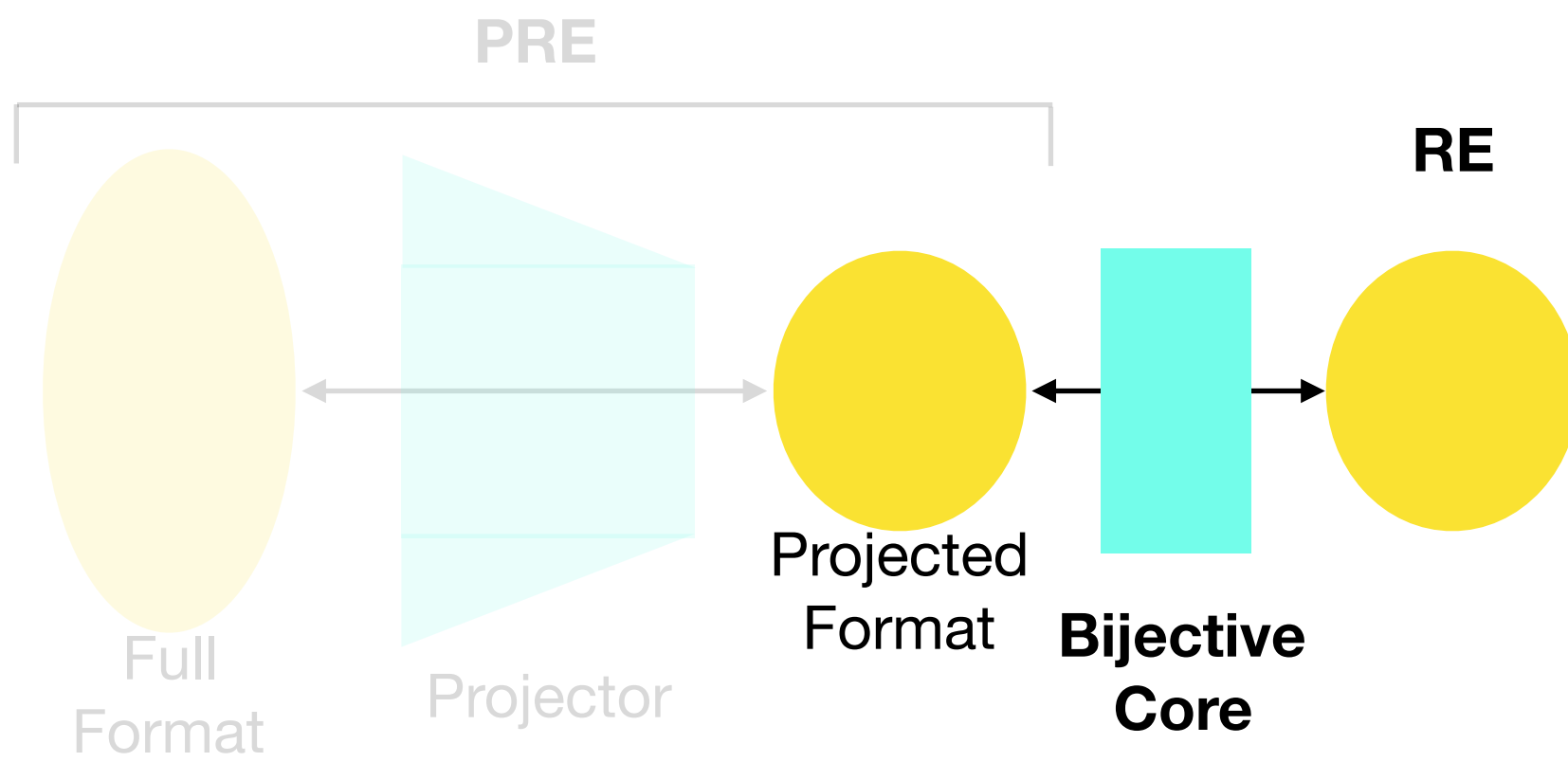


Name . “ , “  
 . skip(Date)

# Asymmetric Lens Synthesis



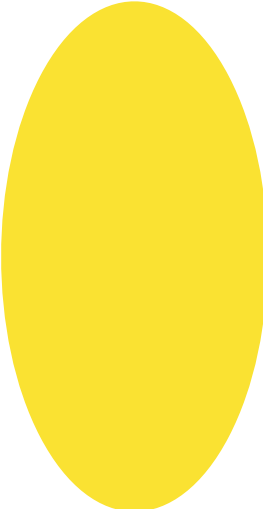




Sibelius, 1865

**PRE**

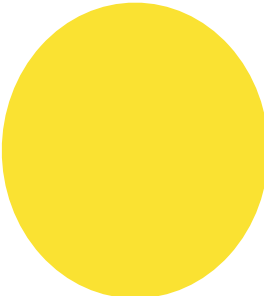
**RE**



Full  
Format



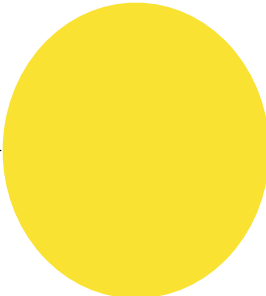
Projector

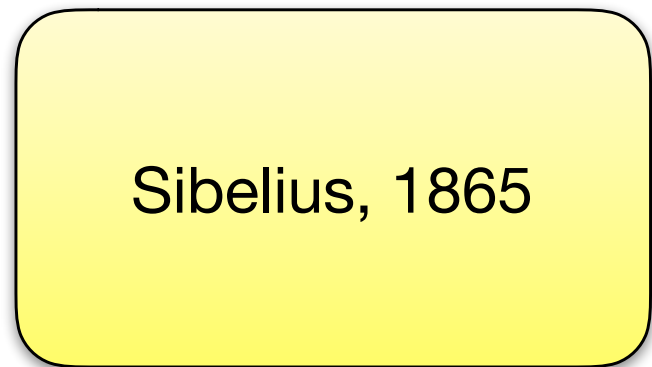


Projected  
Format

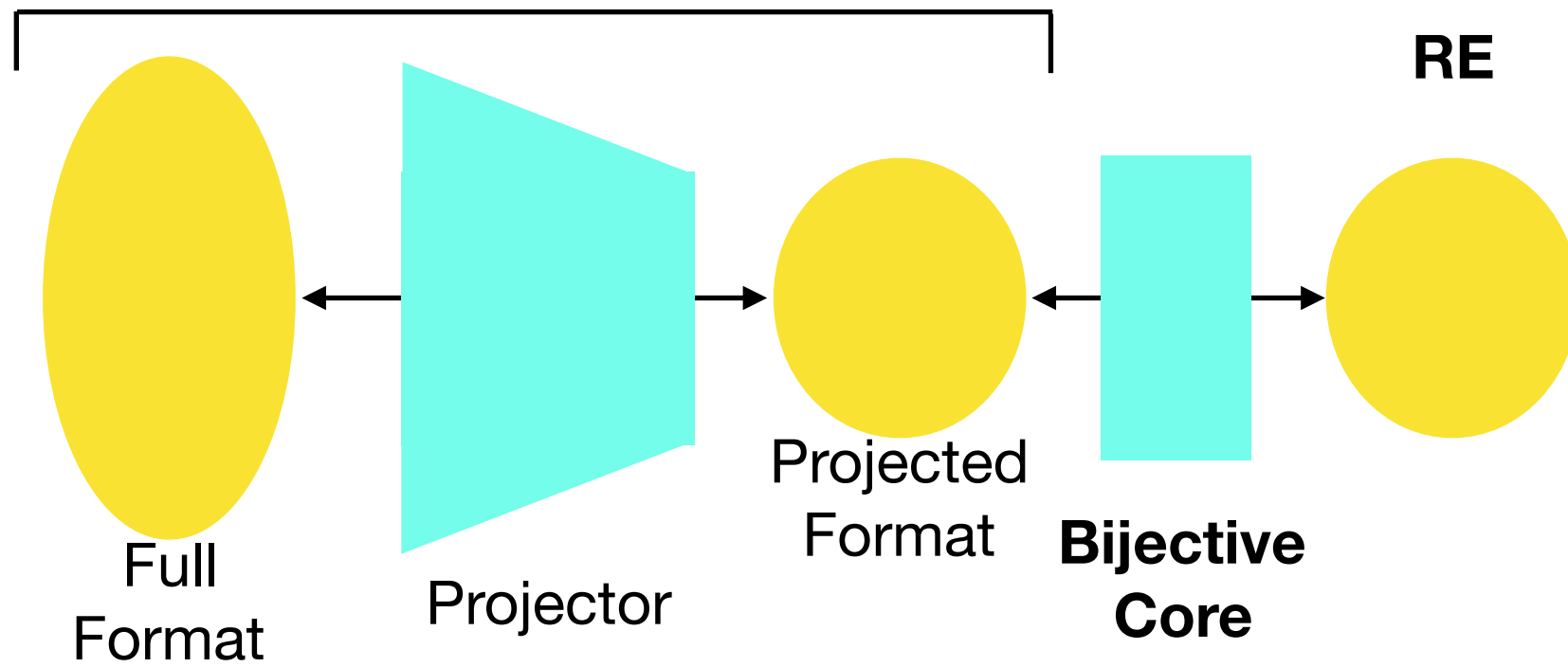


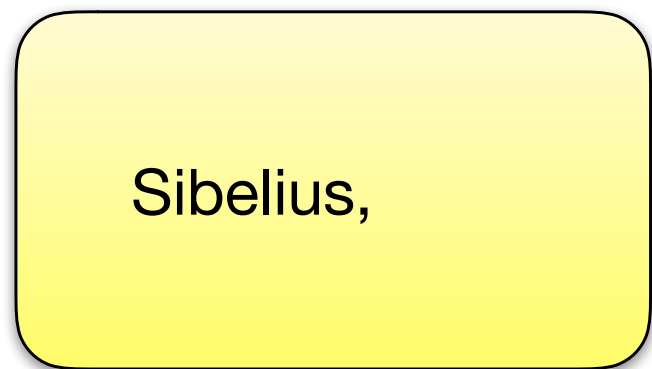
**Bijective  
Core**



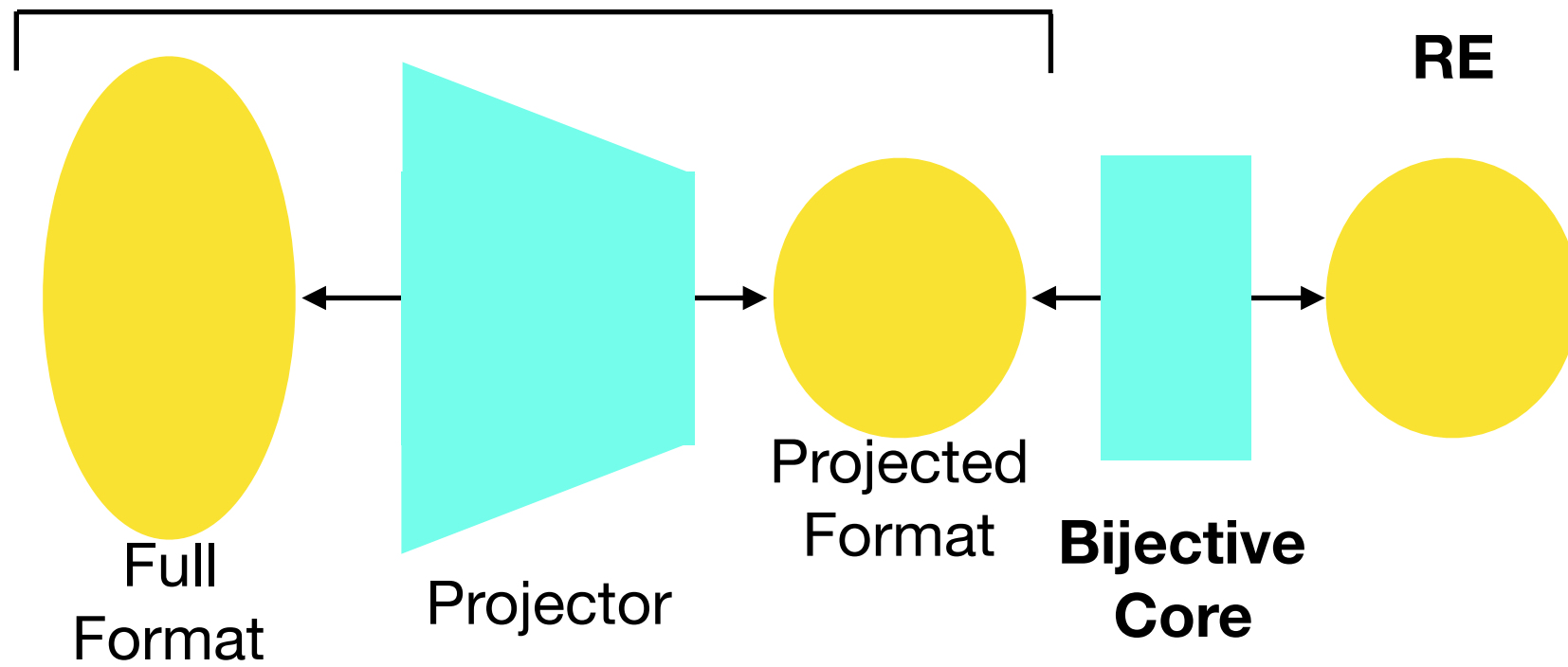


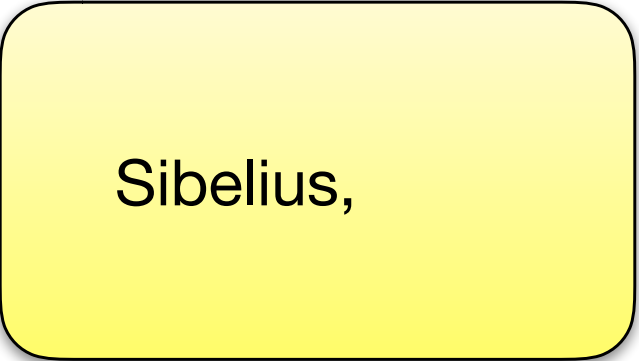
**PRE**





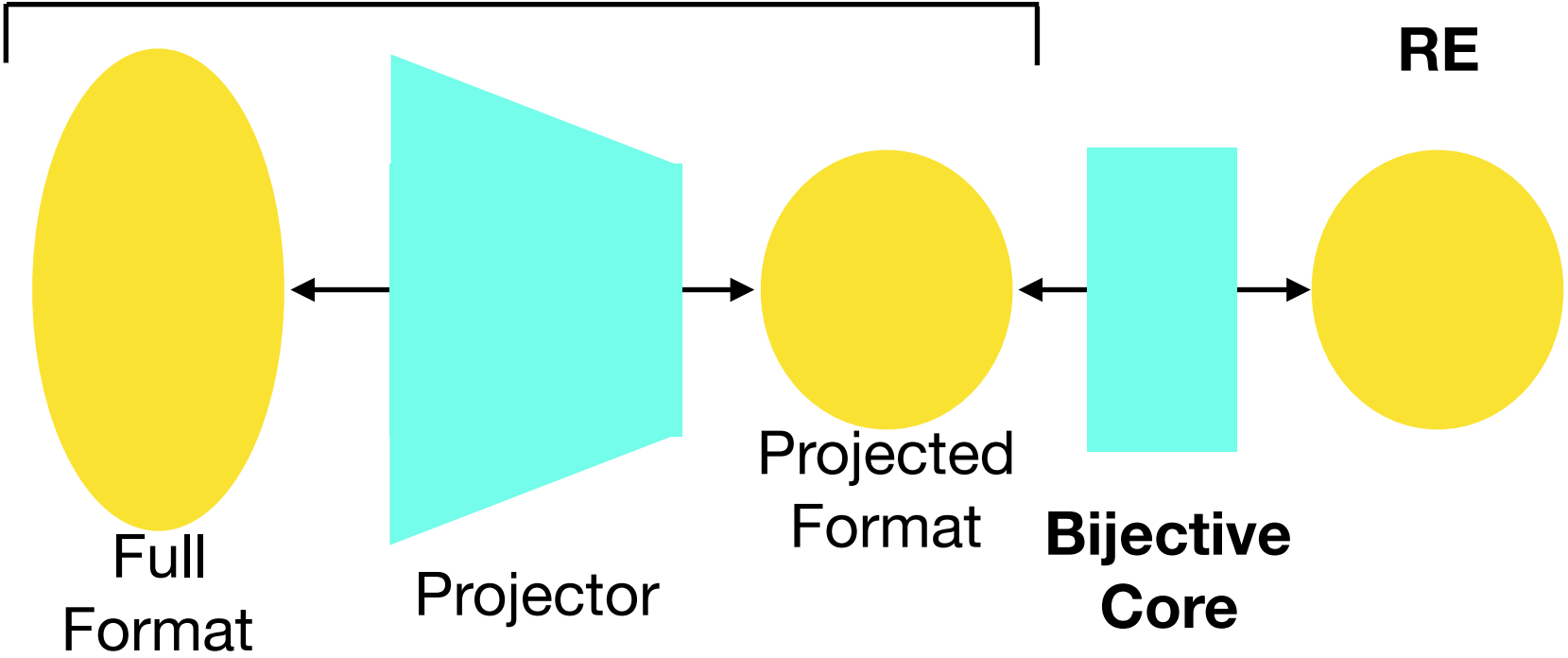
**PRE**

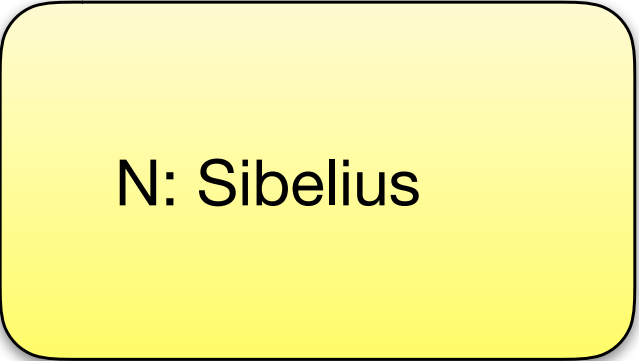




**PRE**

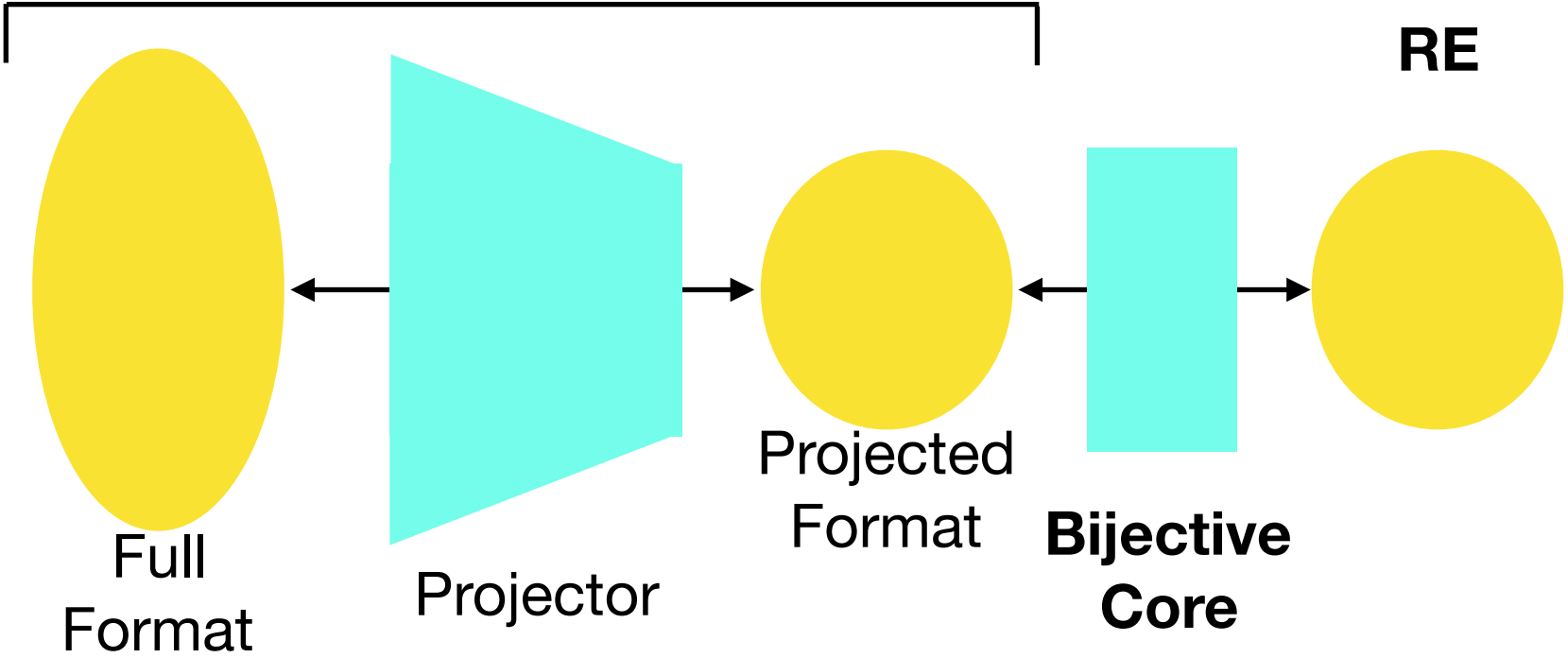
**RE**





**PRE**

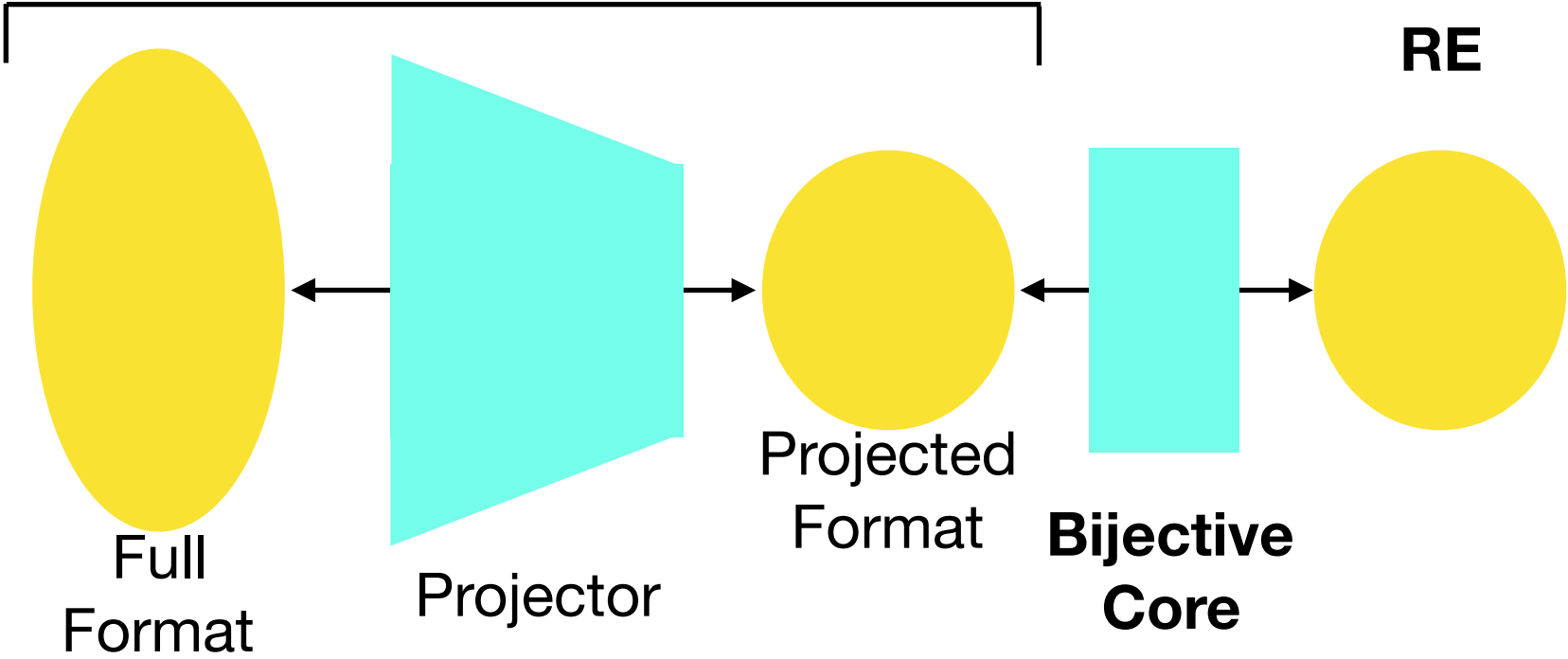
**RE**

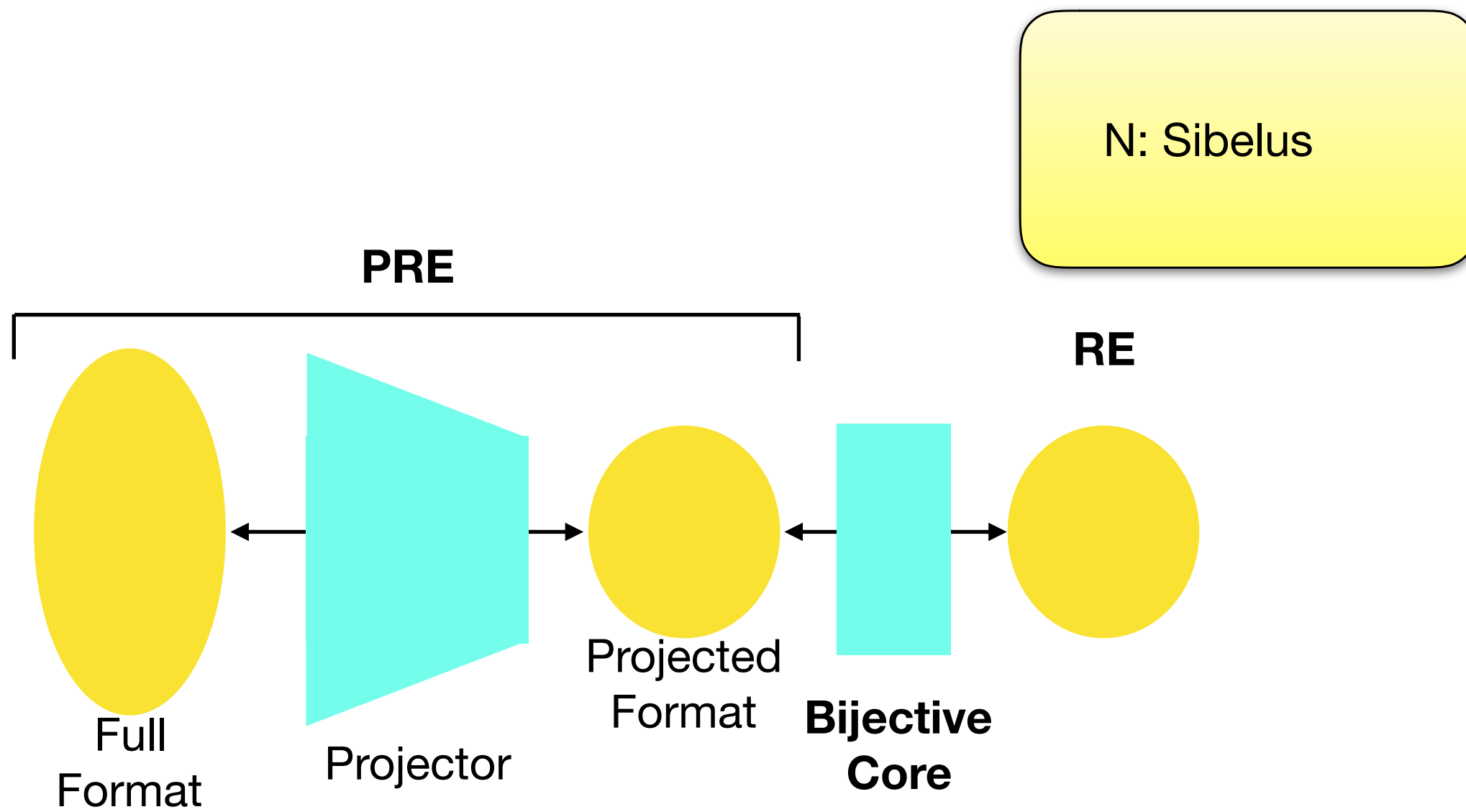


N: Sibelius

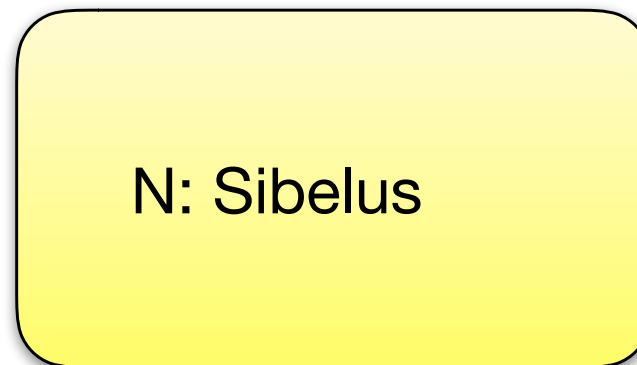
**PRE**

**RE**

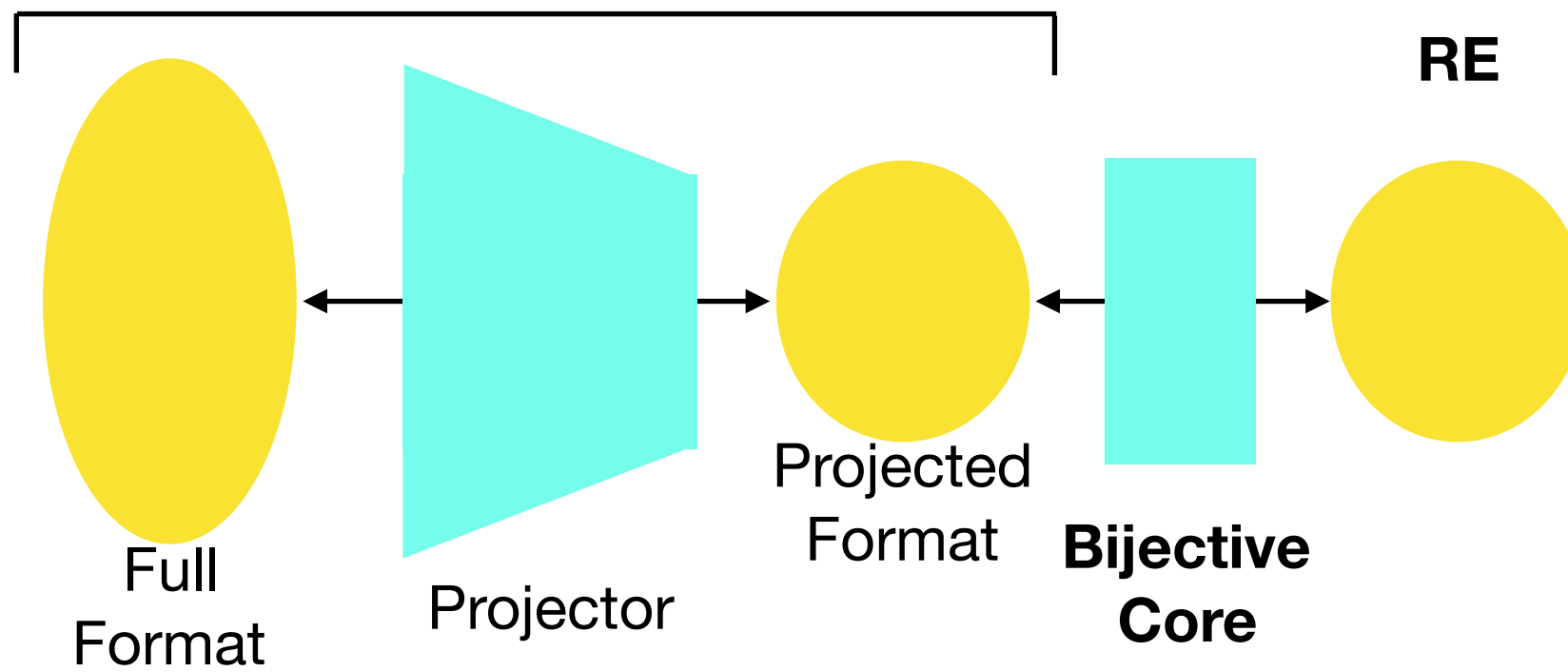


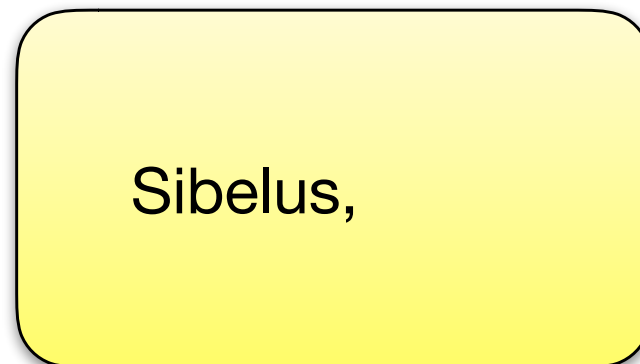




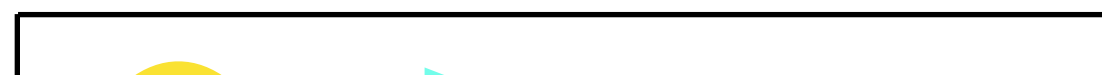


**PRE**

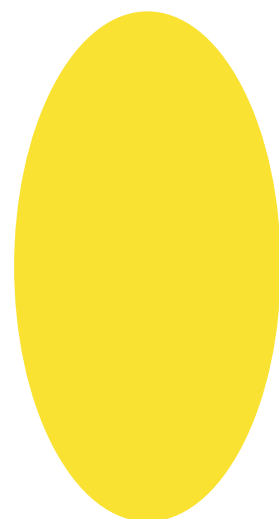




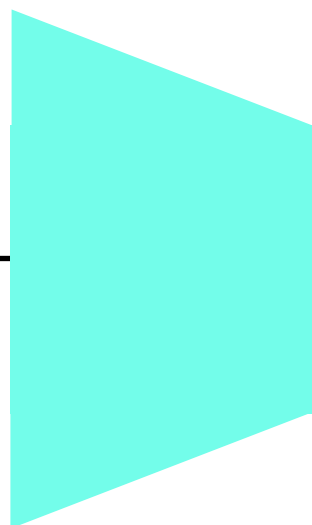
**PRE**



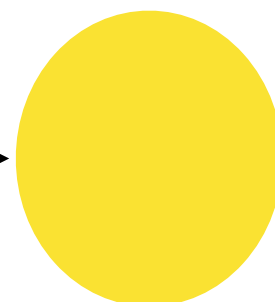
**RE**



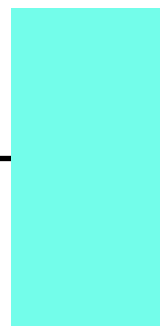
Full  
Format



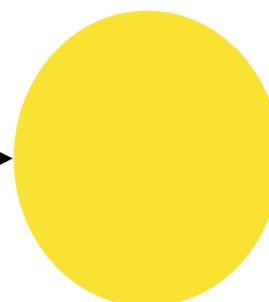
Projector

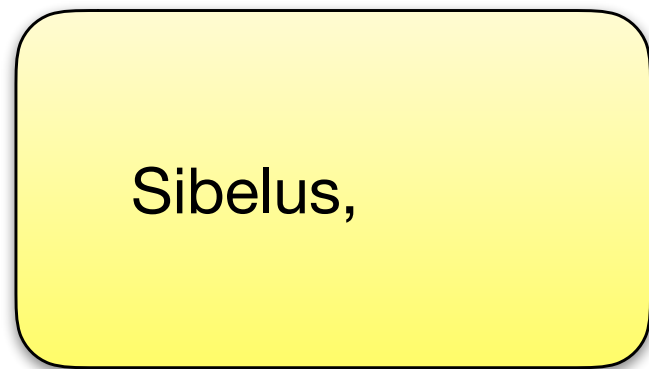


Projected  
Format

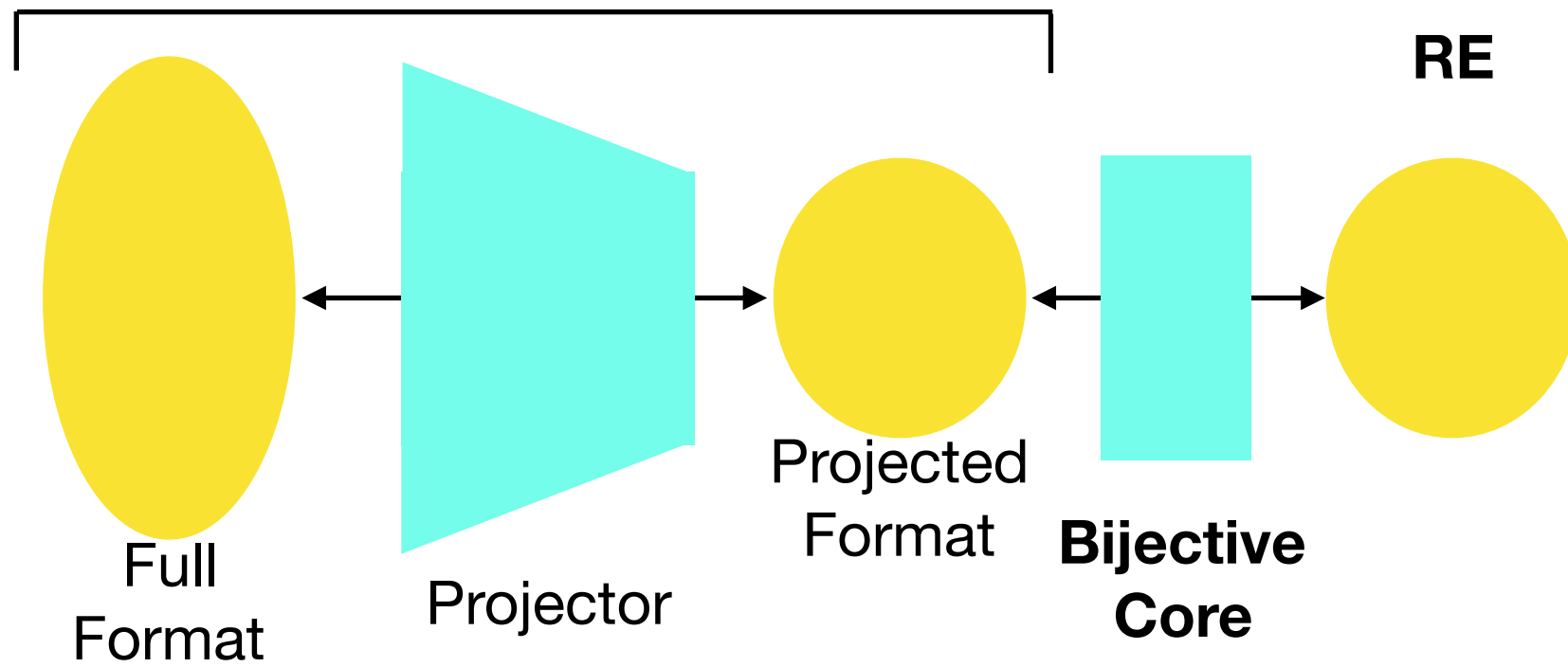


**Bijective  
Core**





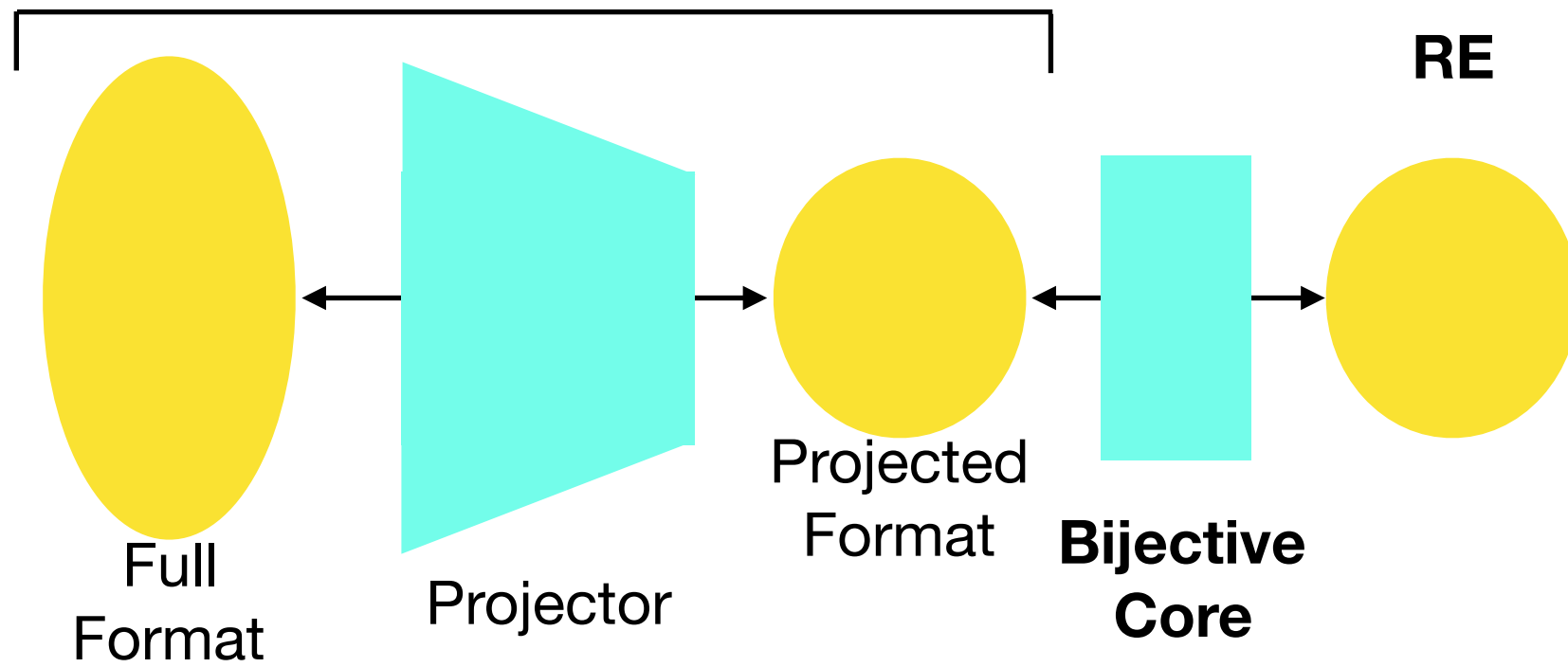
**PRE**

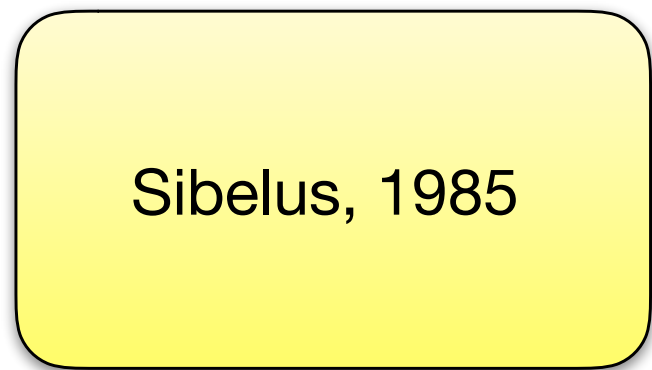


Sibelius, 1985

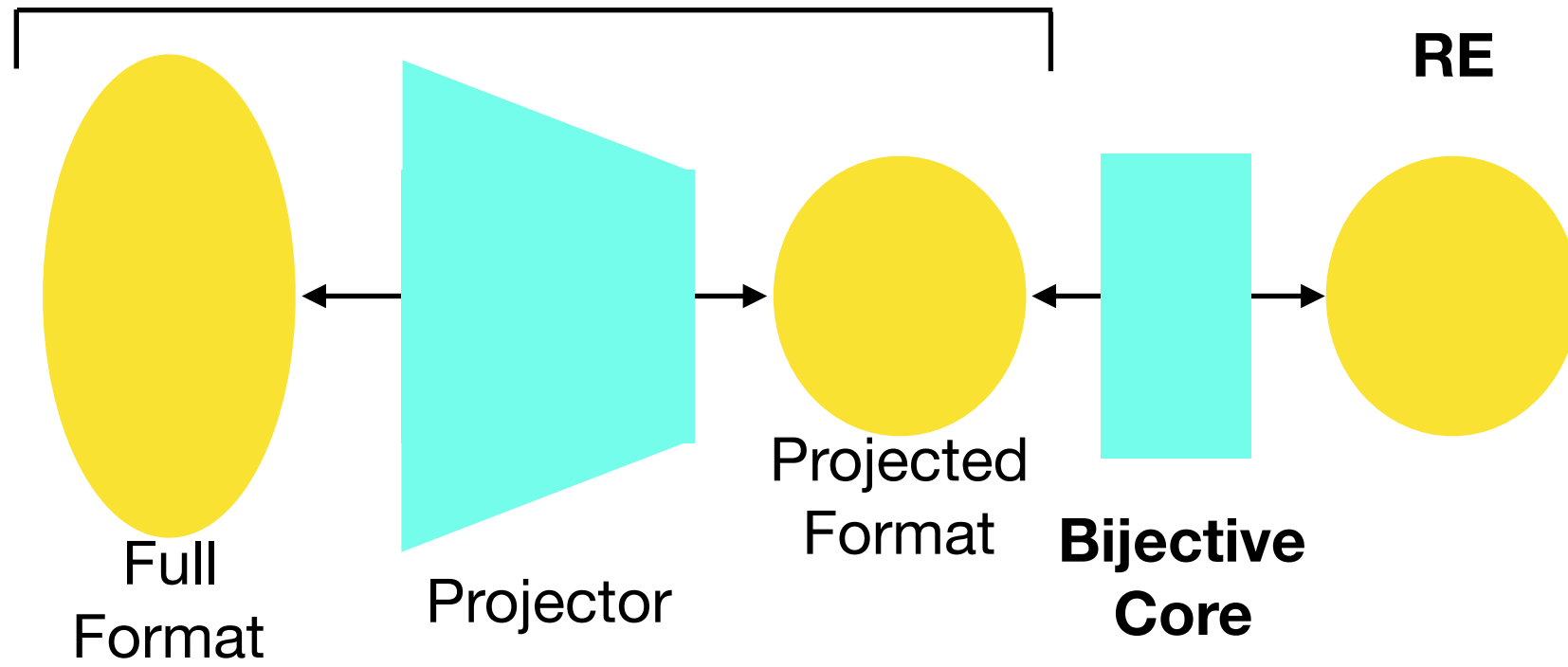
Sibelus,

**PRE**





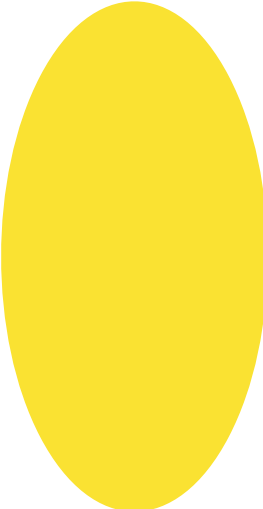
**PRE**



Sibelius, 1985

**PRE**

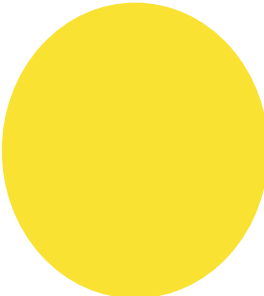
**RE**



Full  
Format



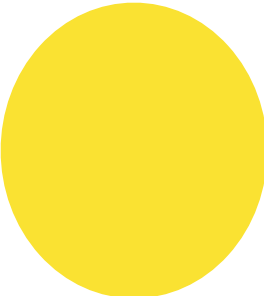
Projector



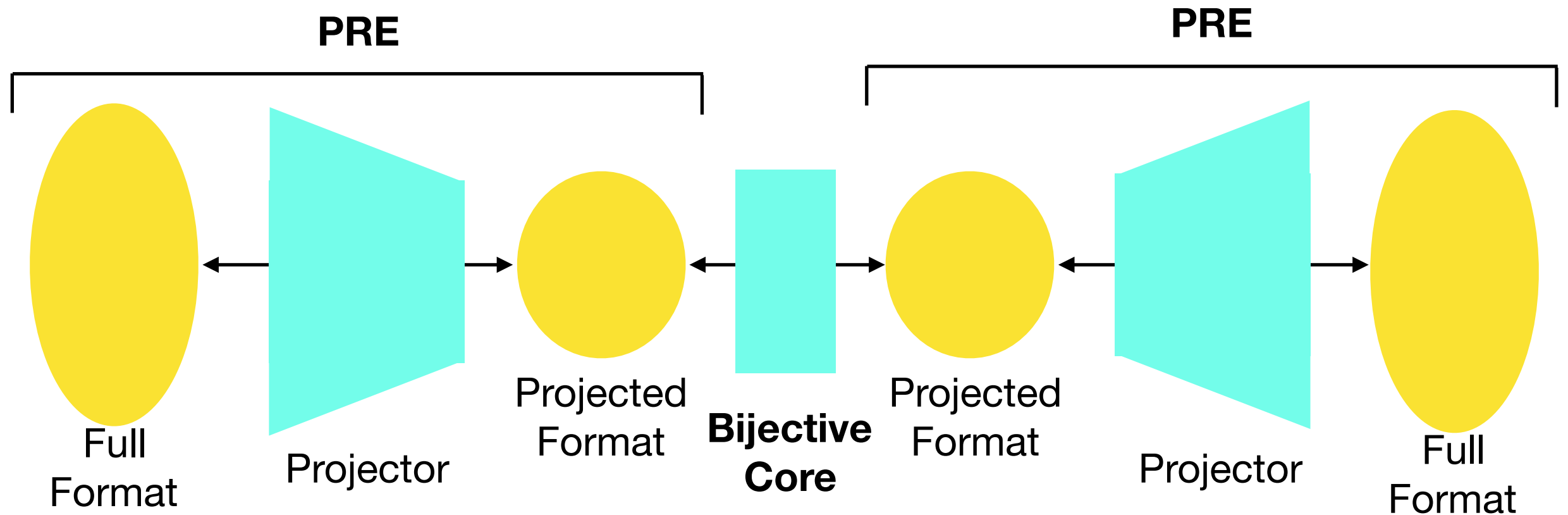
Projected  
Format



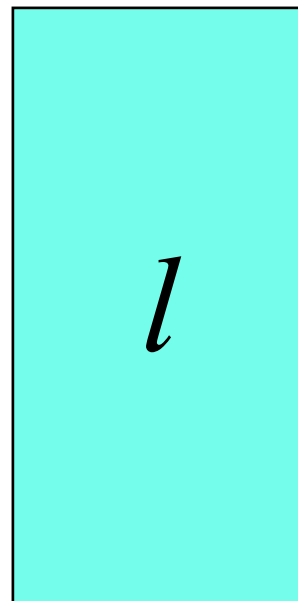
**Bijective  
Core**



# Symmetric Lens Synthesis



# Symmetric Lenses





# Asymmetric Lenses

Sibelius, 1865

*l*

N: Jean Sibelius

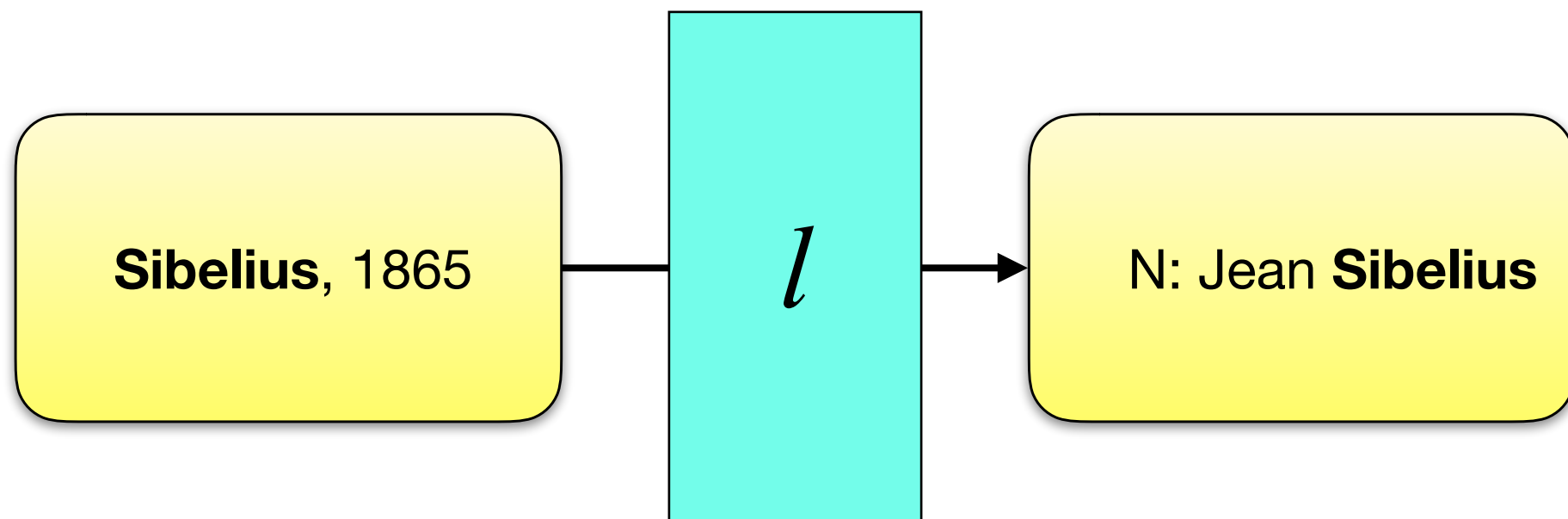
# Asymmetric Lenses

**Sibeliu**, 1865

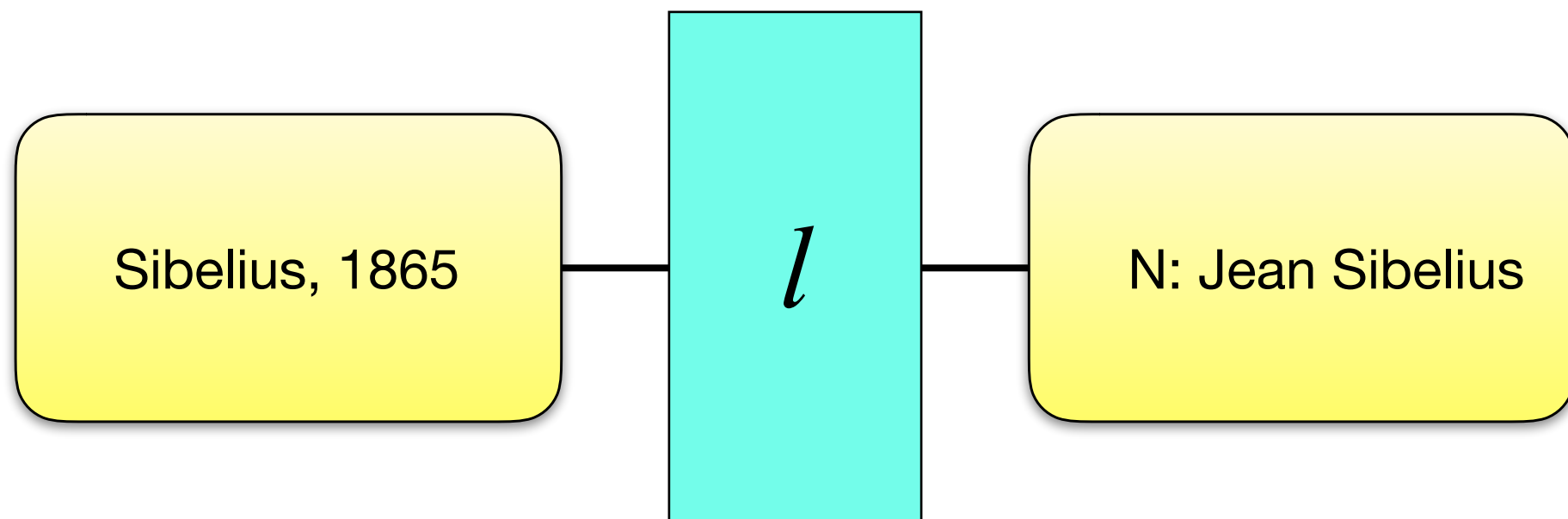
*l*

N: Jean Sibelu

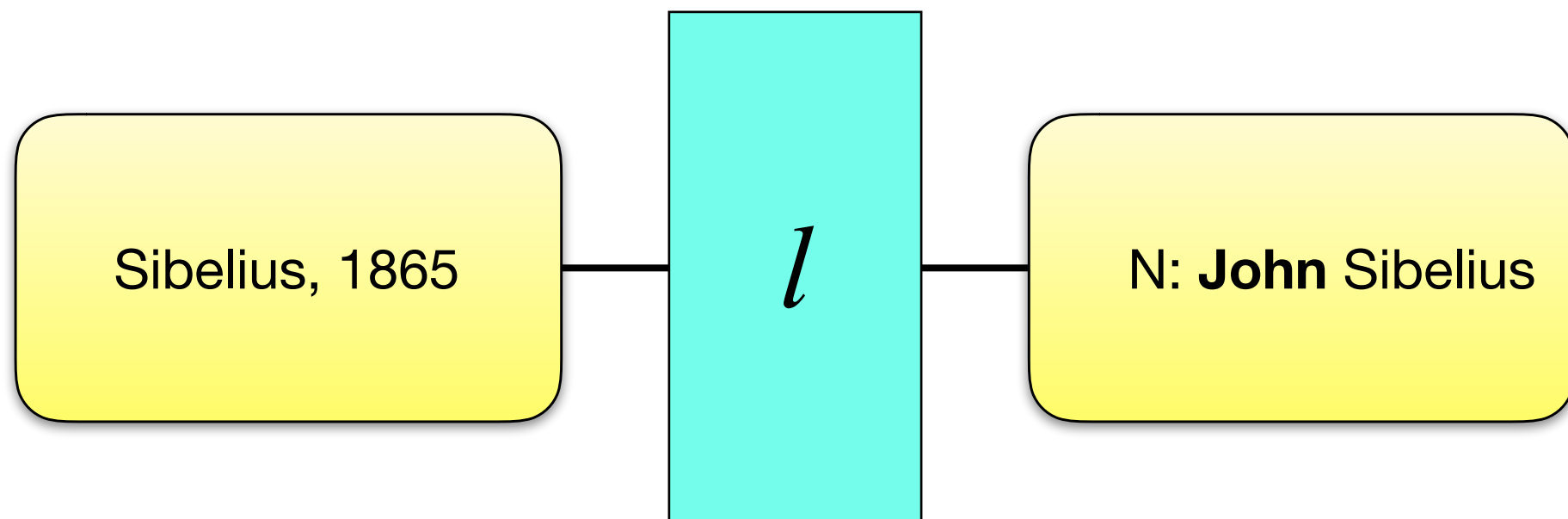
# Asymmetric Lenses



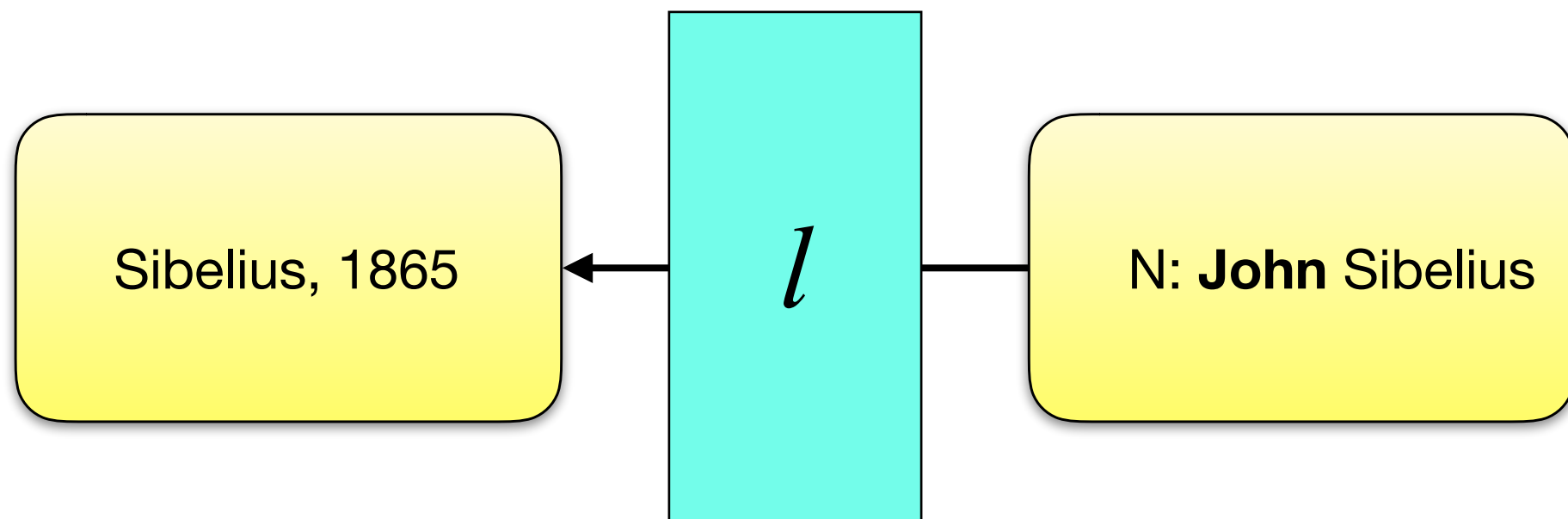
# Asymmetric Lenses



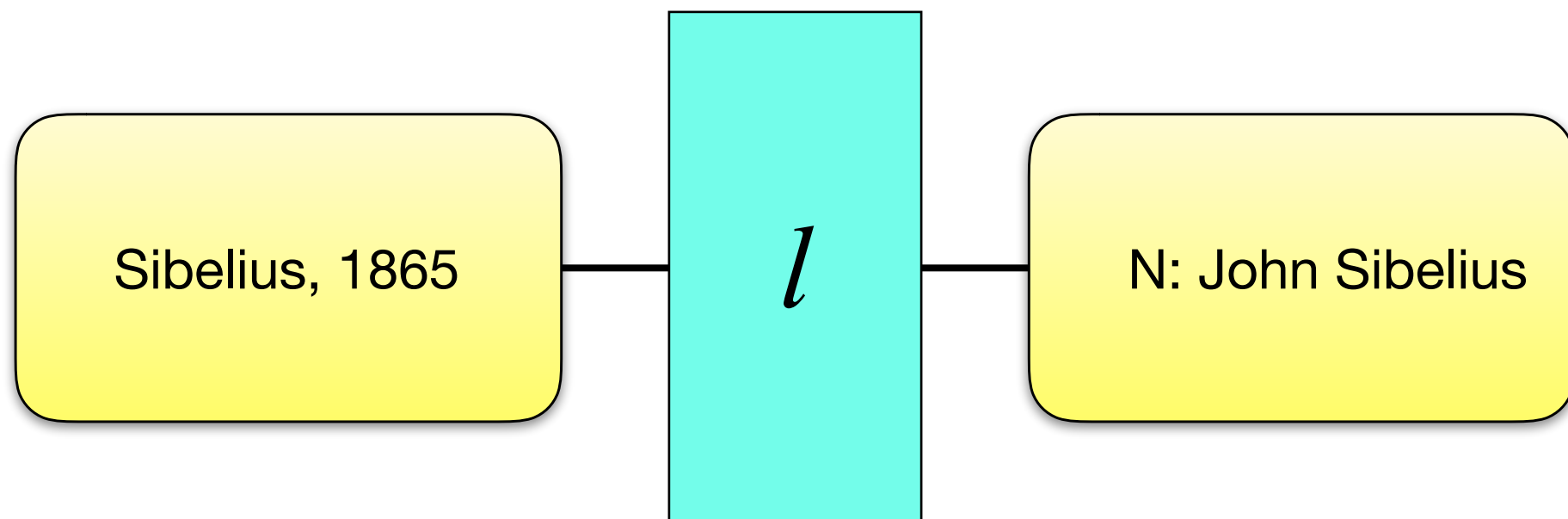
# Asymmetric Lenses



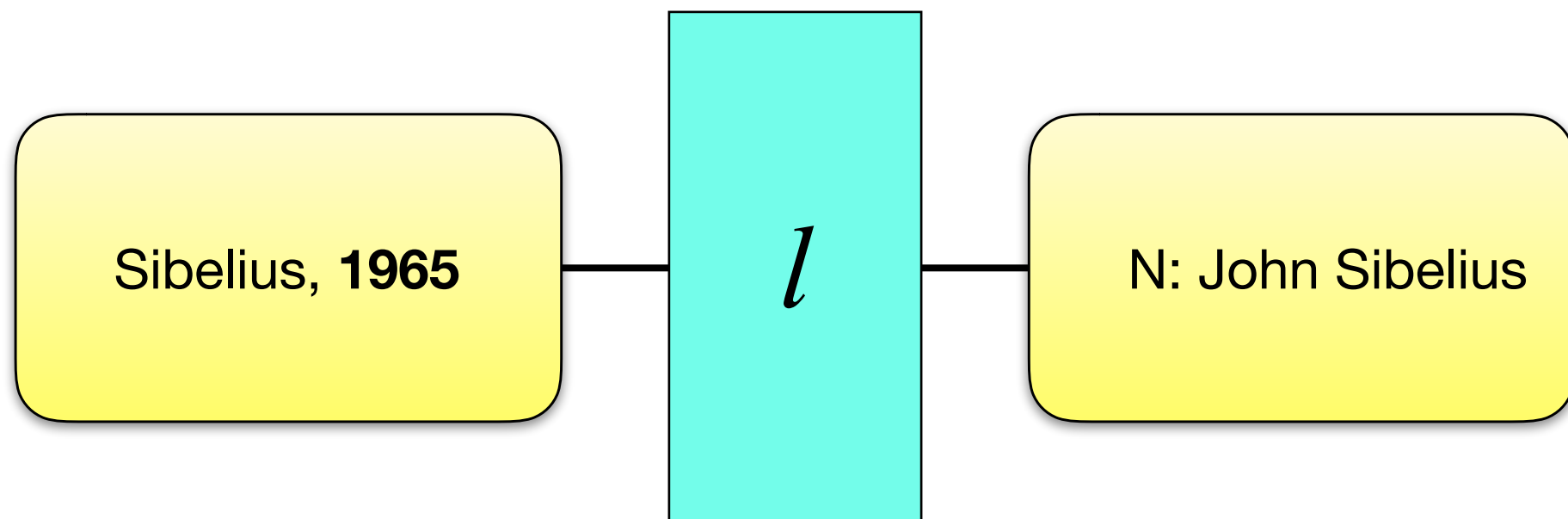
# Asymmetric Lenses



# Asymmetric Lenses

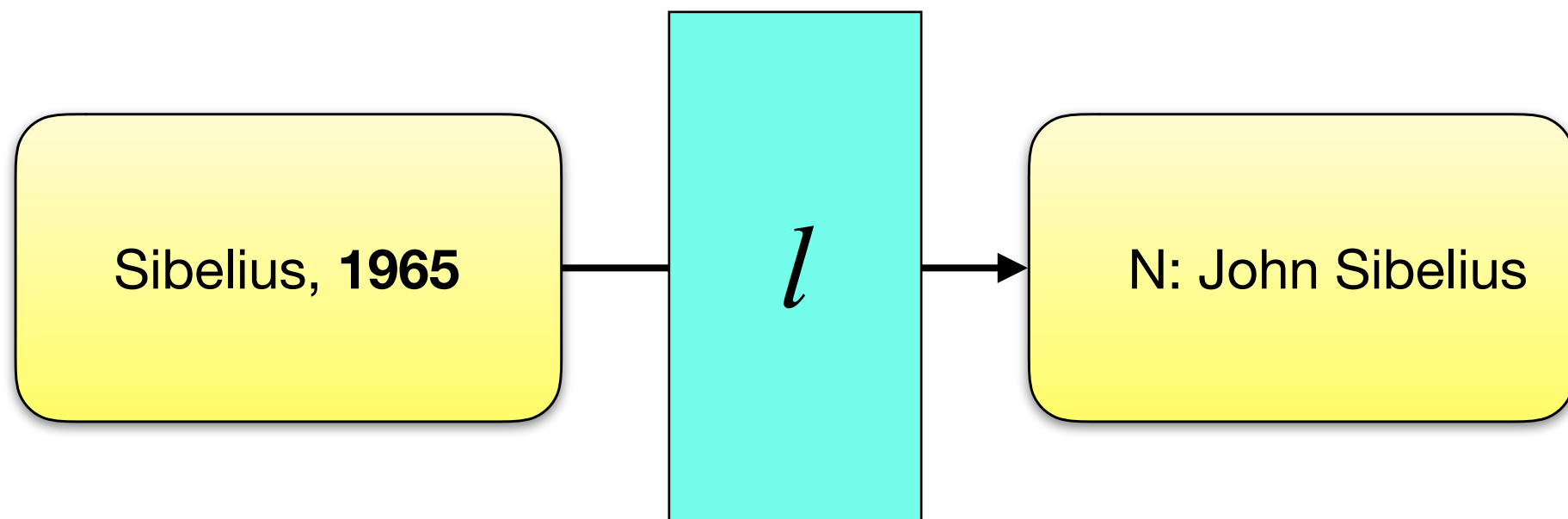


# Asymmetric Lenses

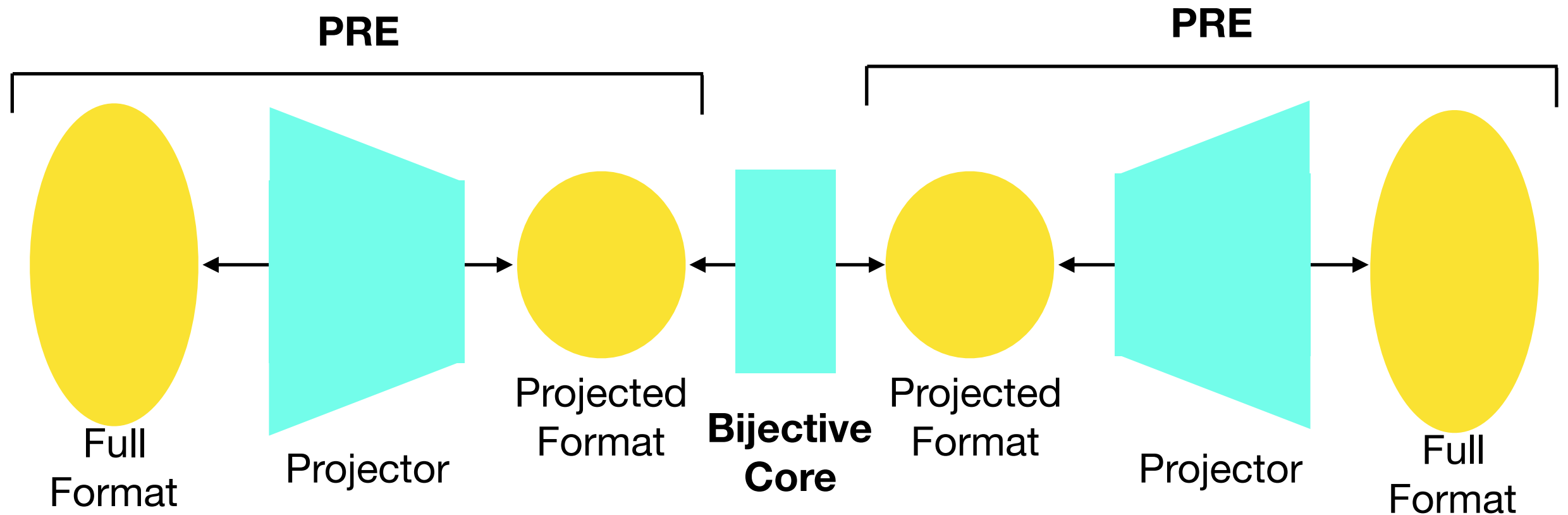




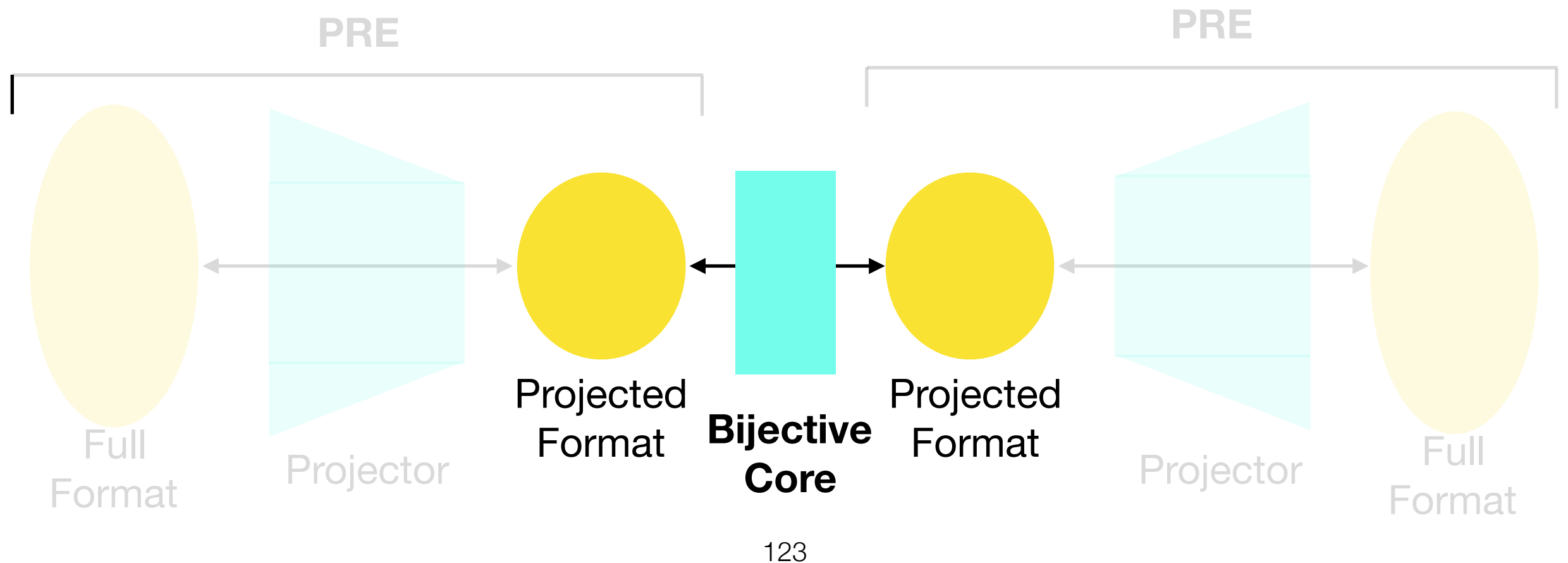
# Asymmetric Lenses



# Symmetric Lens Synthesis



# Symmetric Lens Synthesis



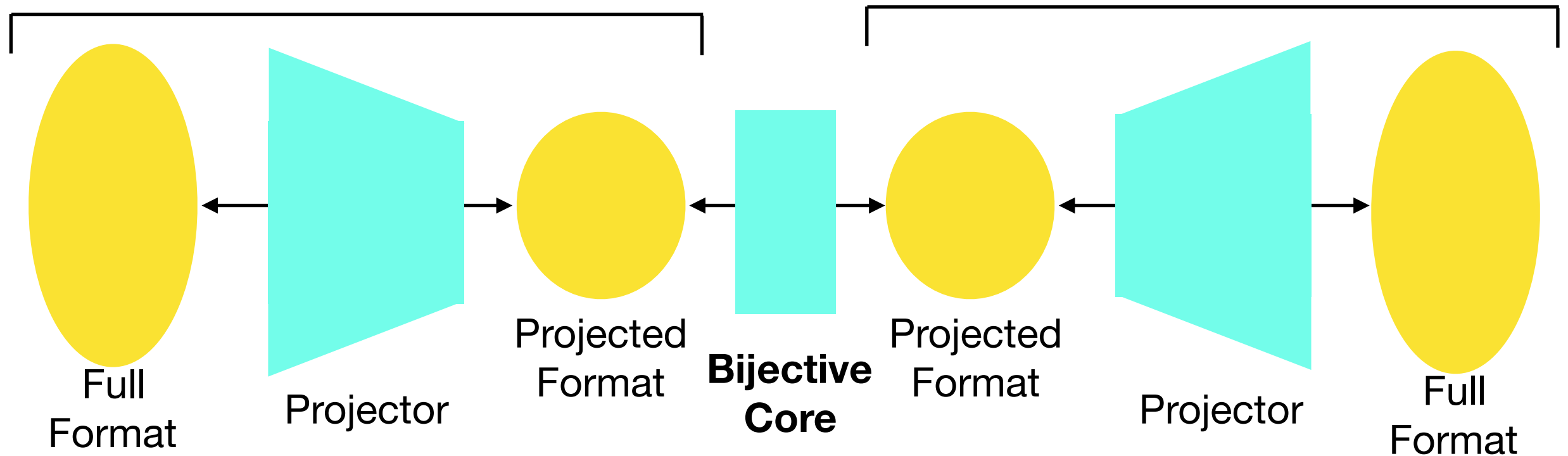
# Symmetric Lens Synthesis

Sibelius, 1865

Jean Sibelius

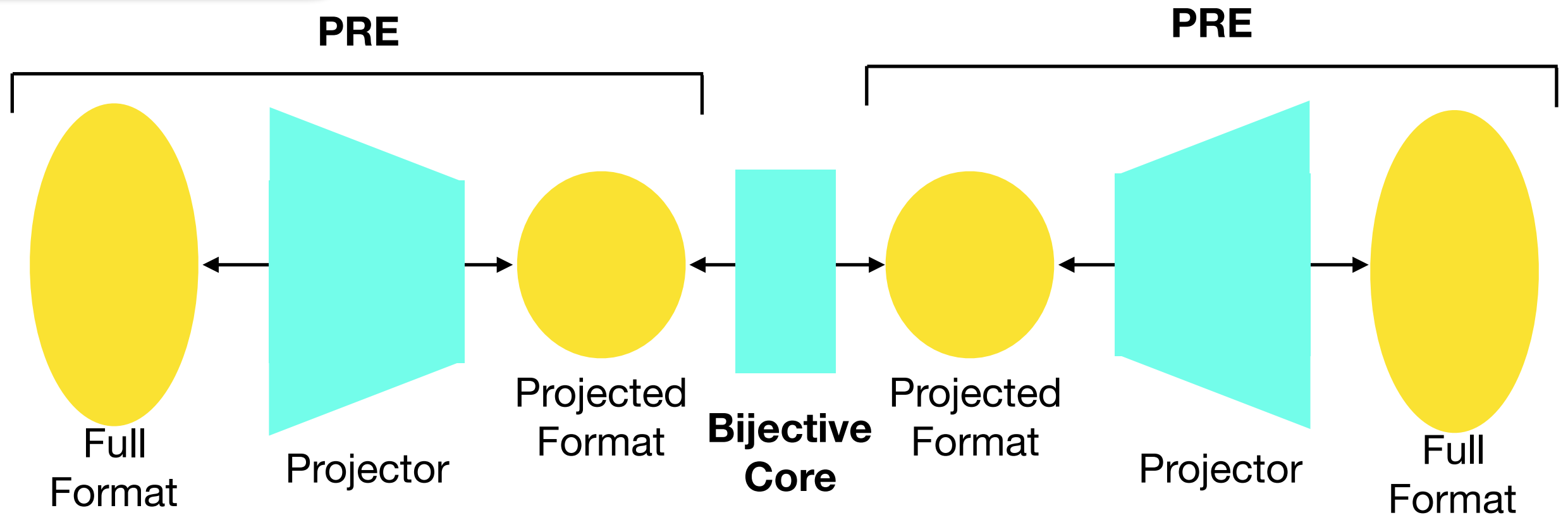
PRE

PRE

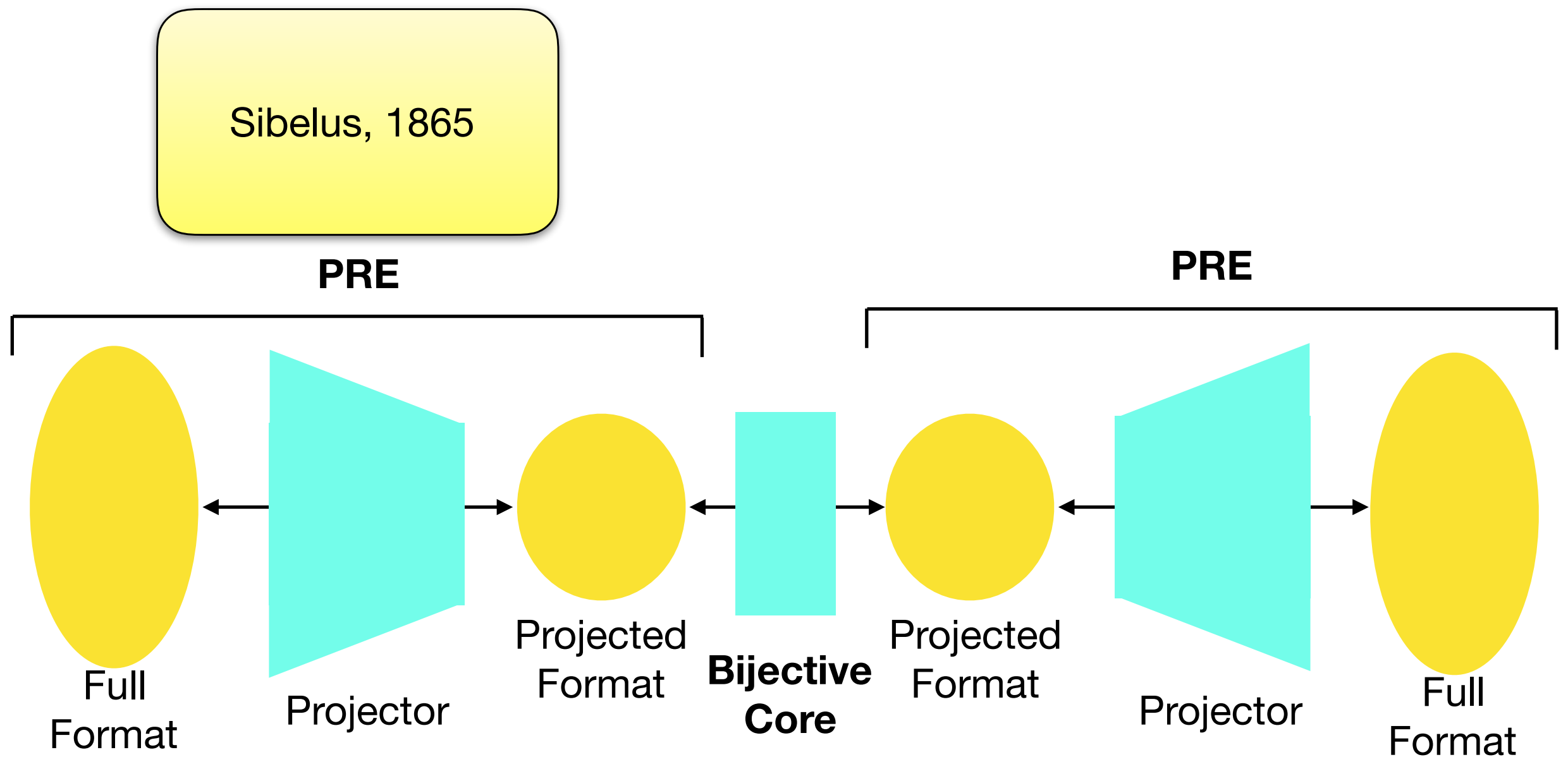


# Symmetric Lens Synthesis

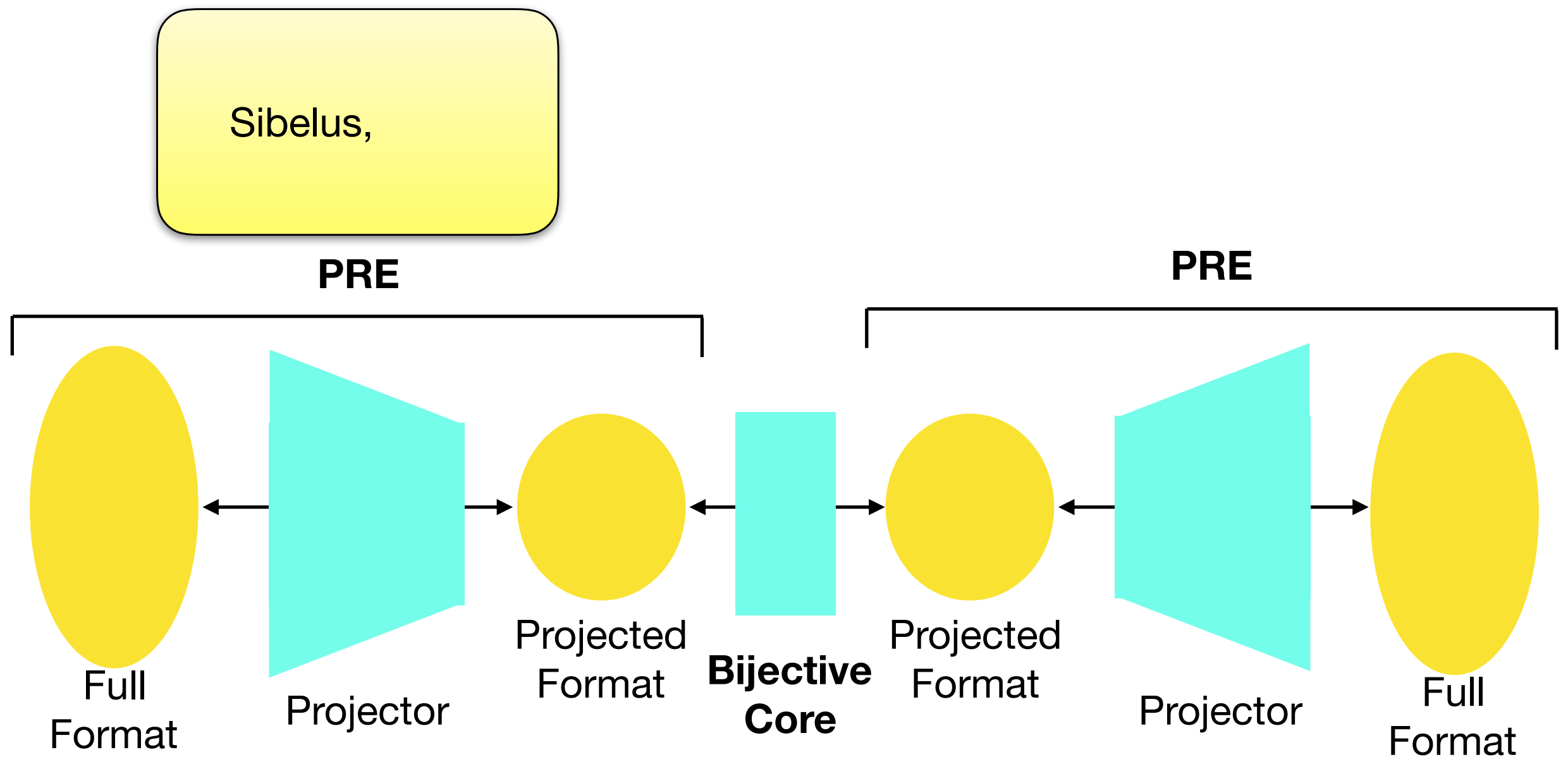
Sibelus, 1865



# Symmetric Lens Synthesis



# Symmetric Lens Synthesis

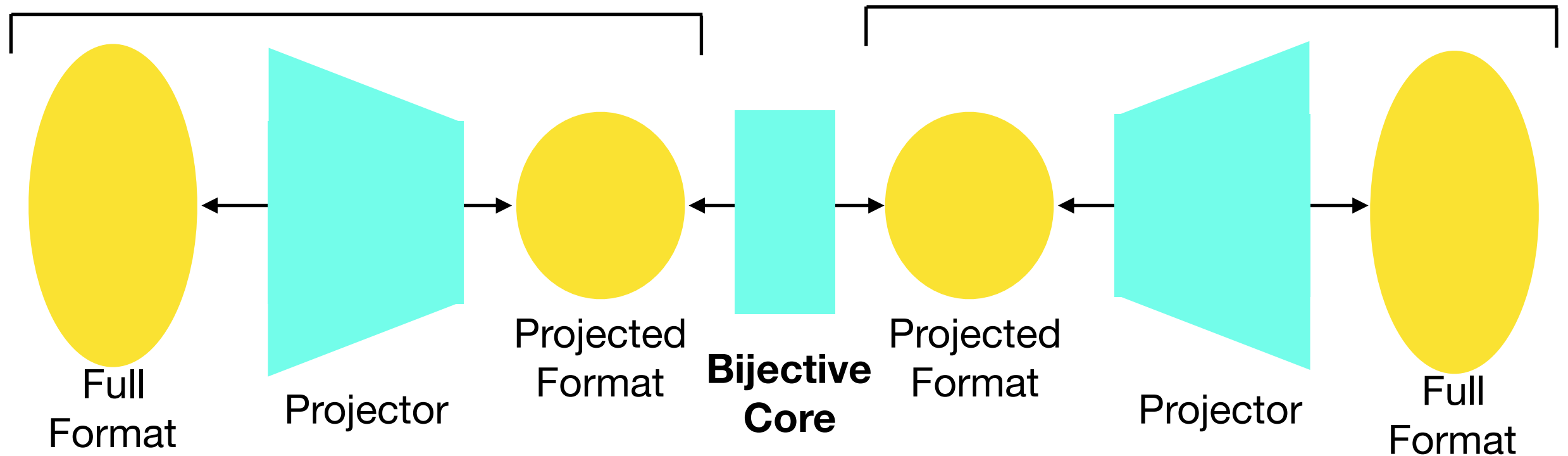


# Symmetric Lens Synthesis

Sibelus,

PRE

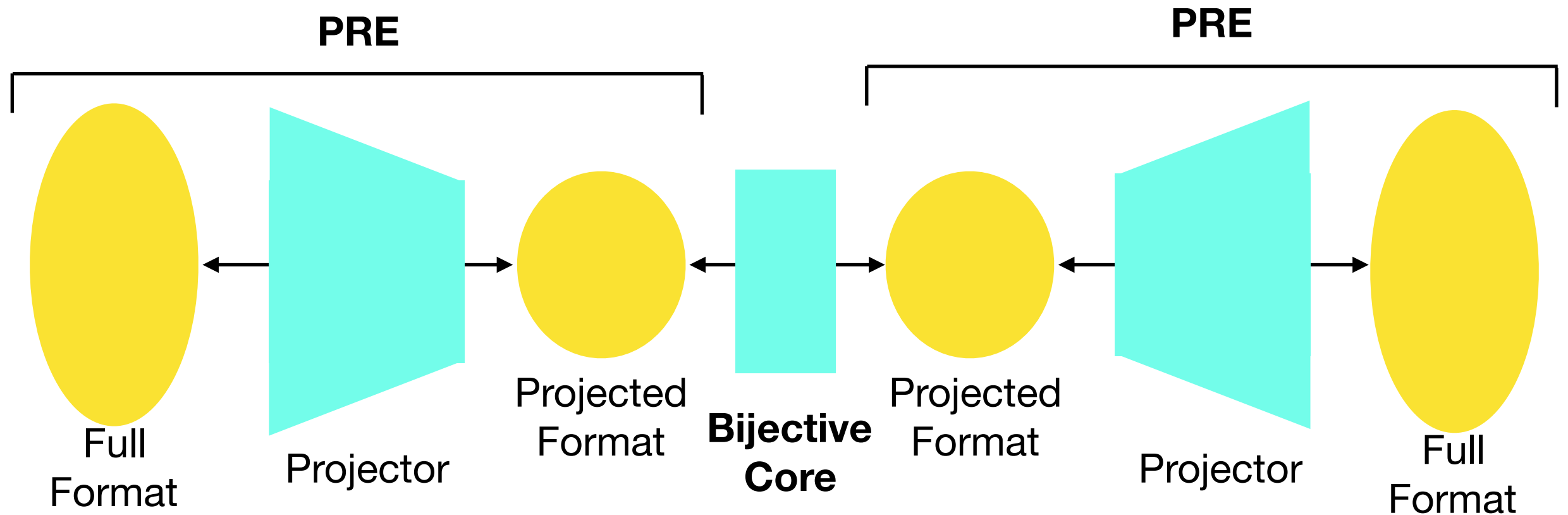
PRE



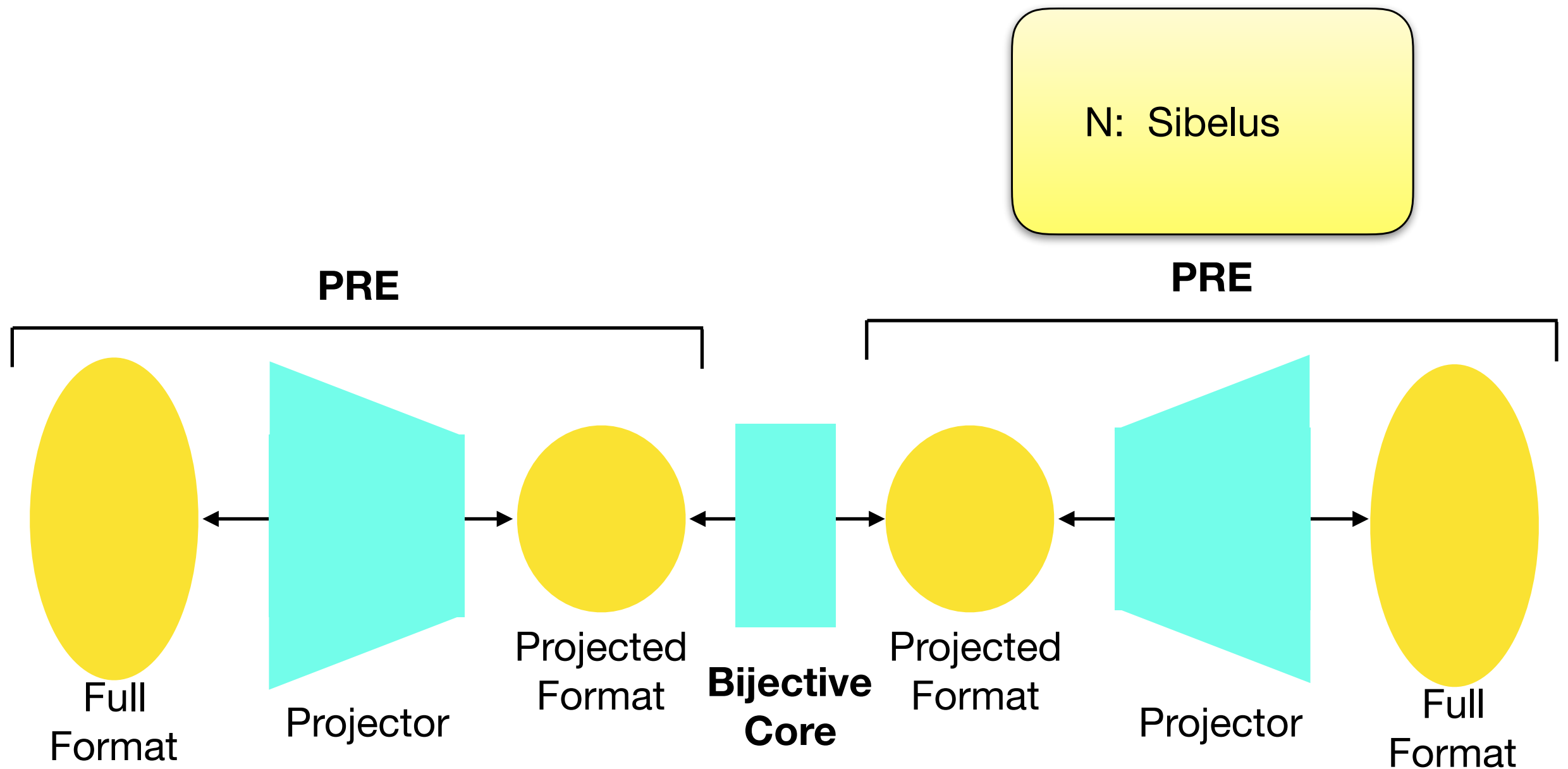


# Symmetric Lens Synthesis

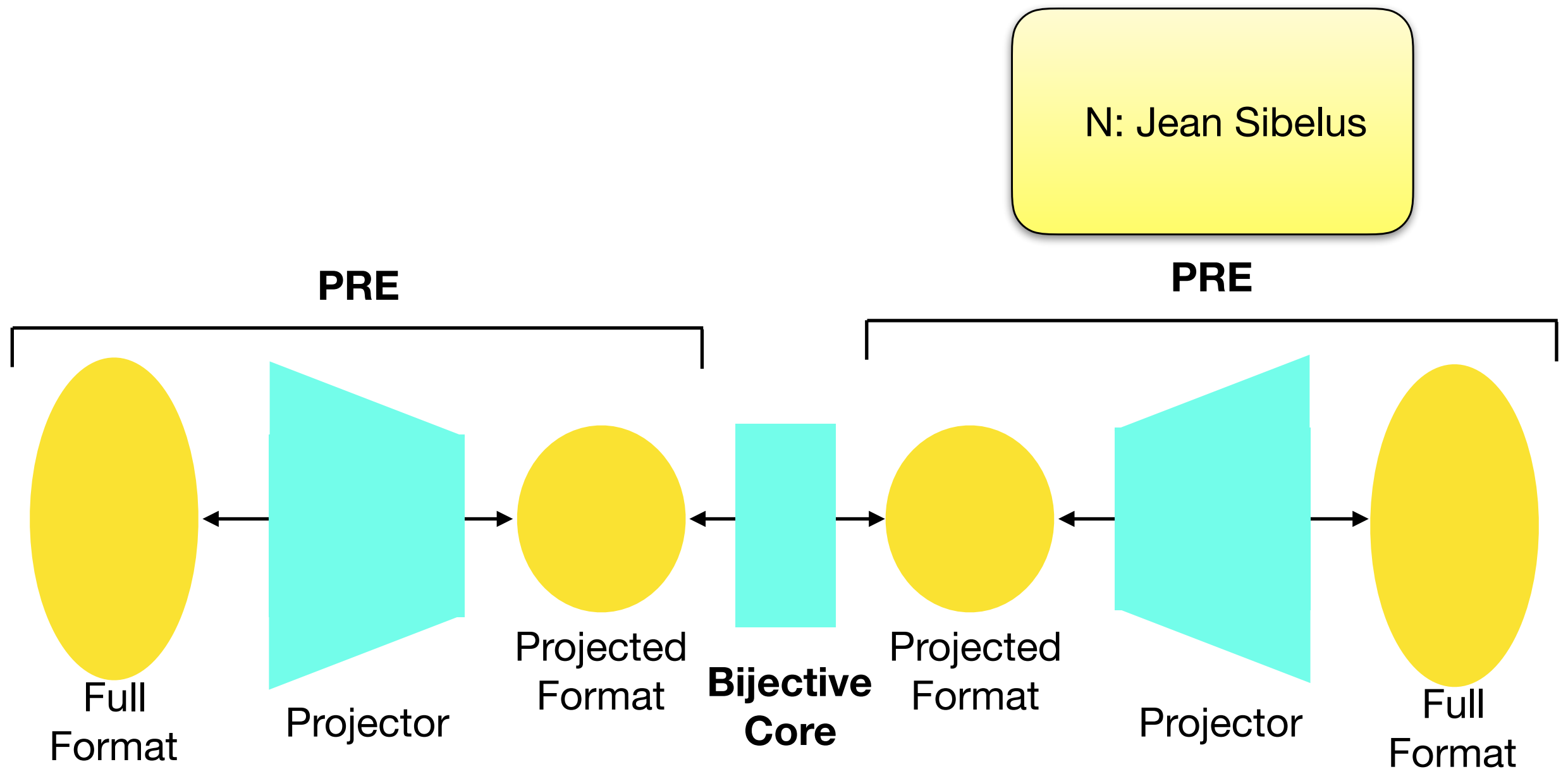
N: Sibelius



# Symmetric Lens Synthesis

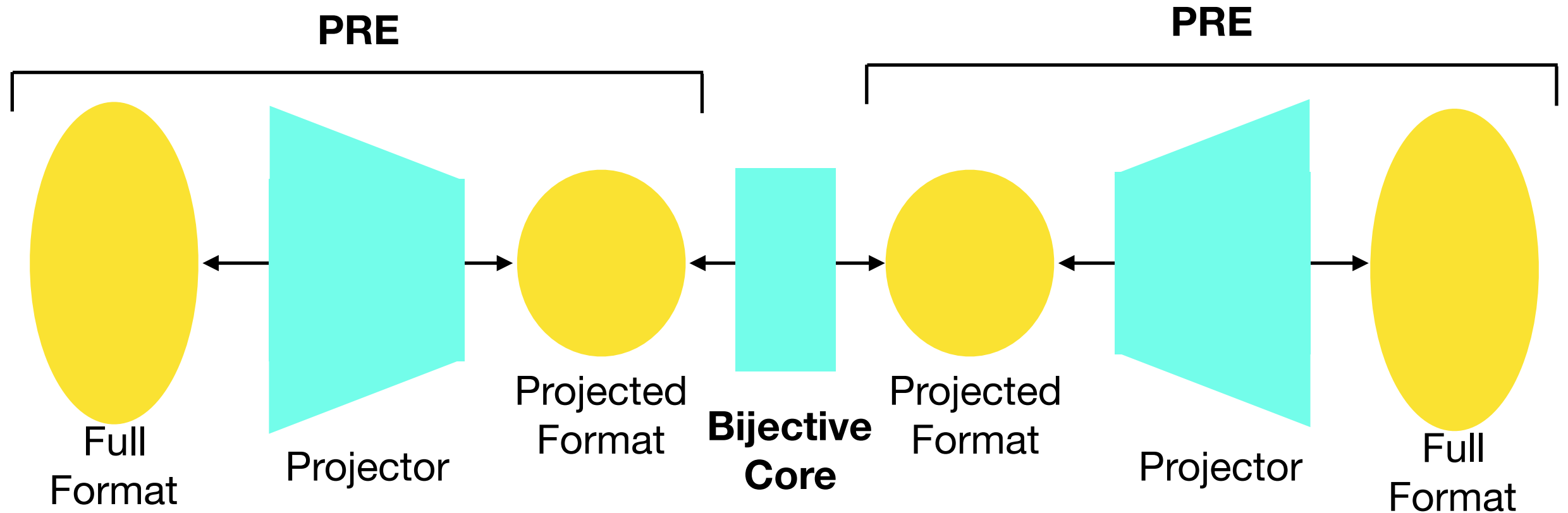


# Symmetric Lens Synthesis



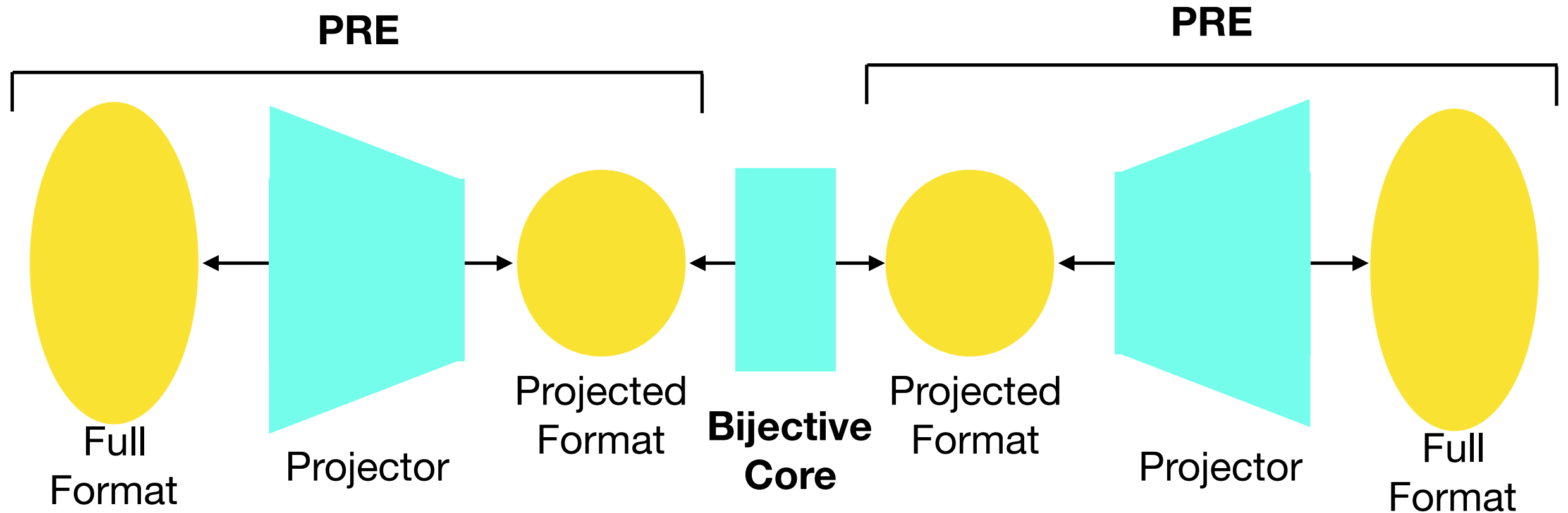
# Symmetric Lens Synthesis

N: Jean Sibelus



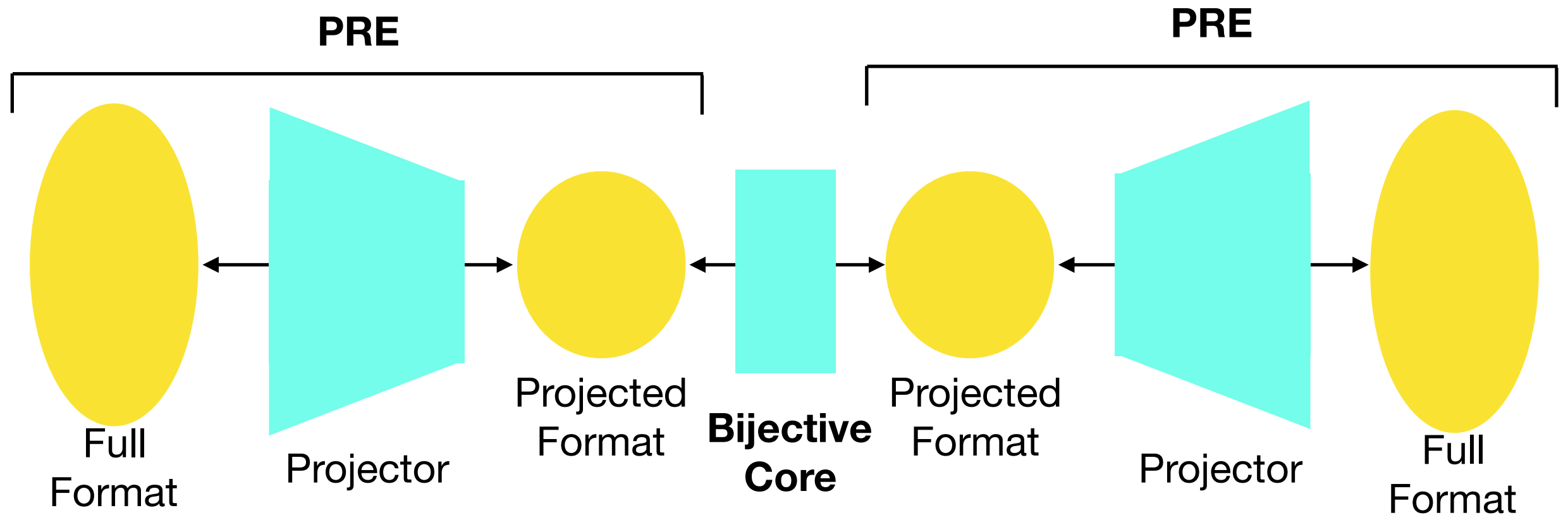
# Symmetric Lens Synthesis

N: Jean Sibelius

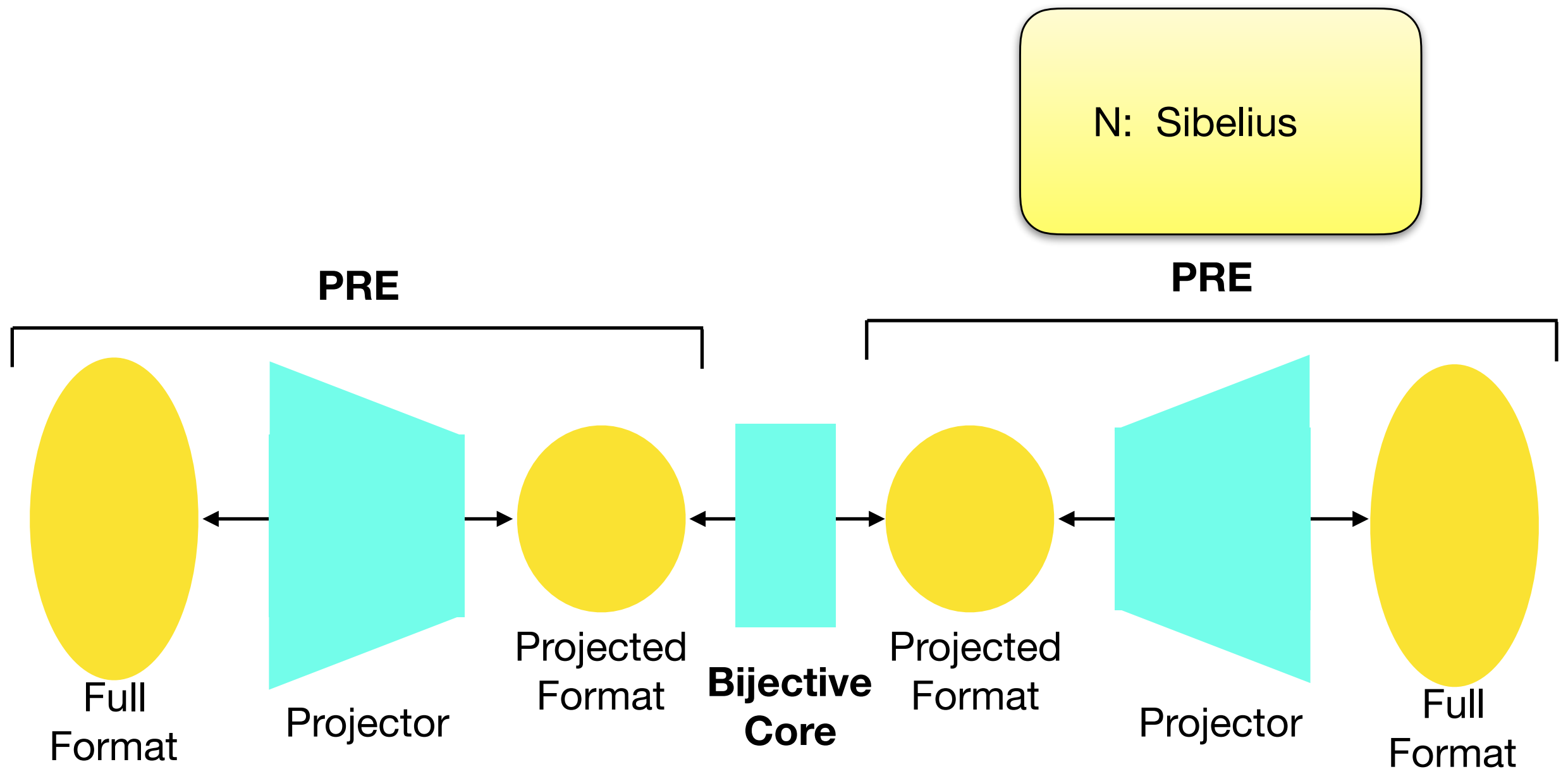


# Symmetric Lens Synthesis

N: Jean Sibelius

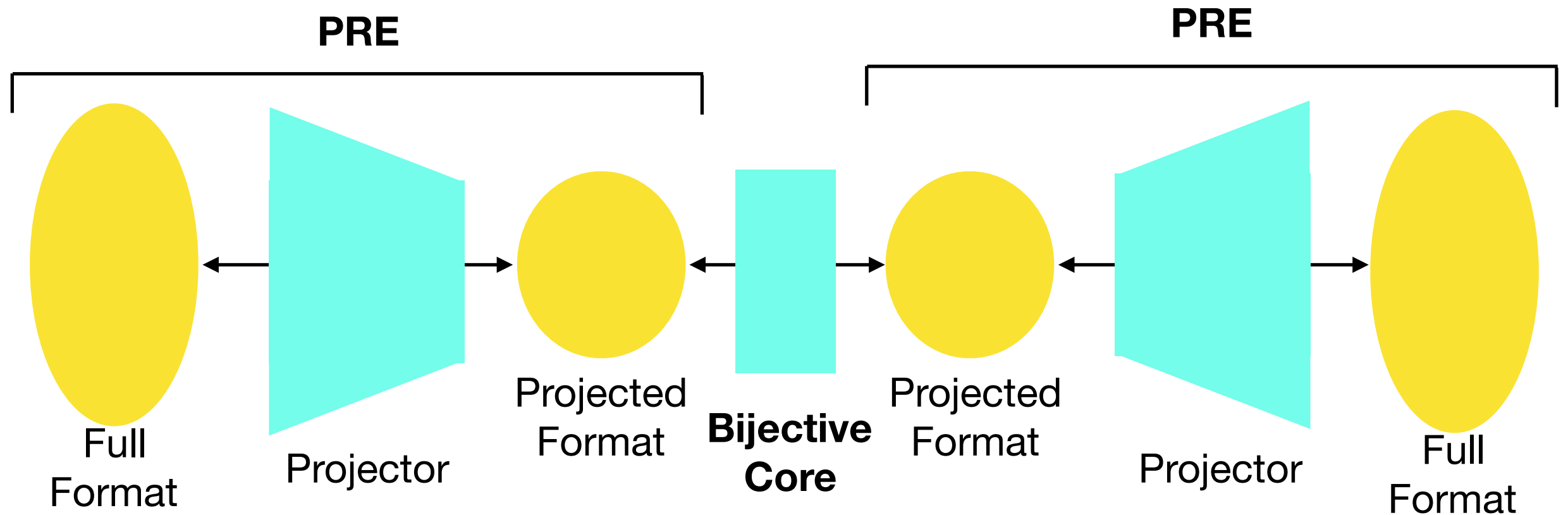


# Symmetric Lens Synthesis



# Symmetric Lens Synthesis

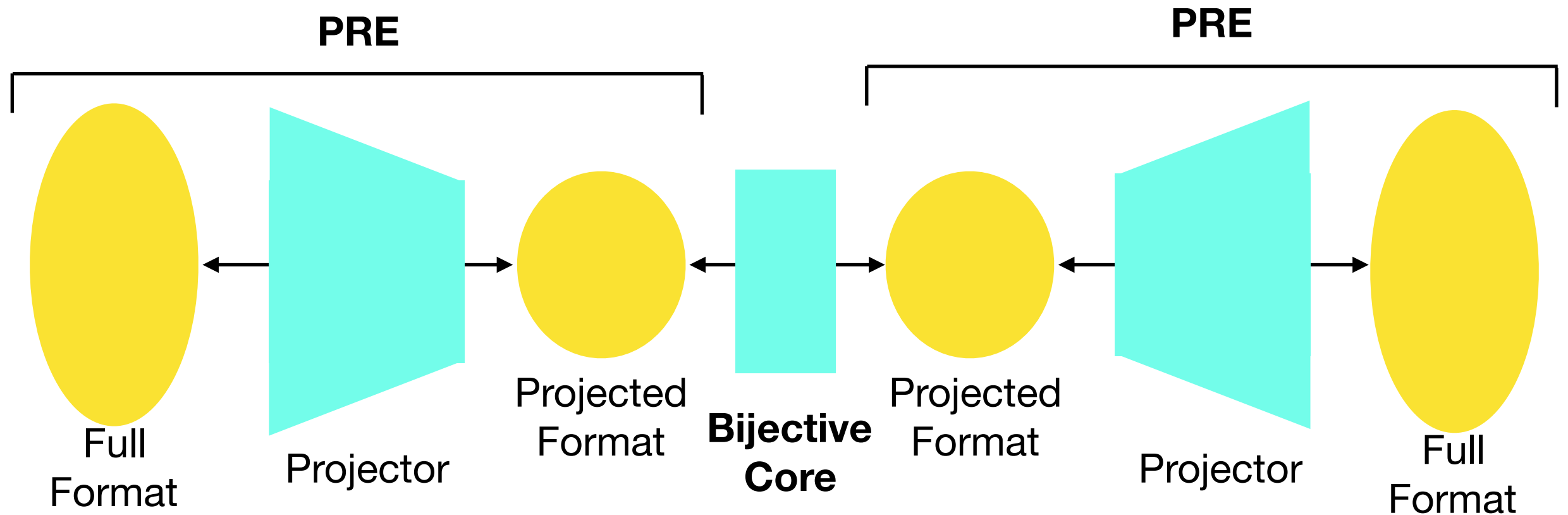
N: Sibelius



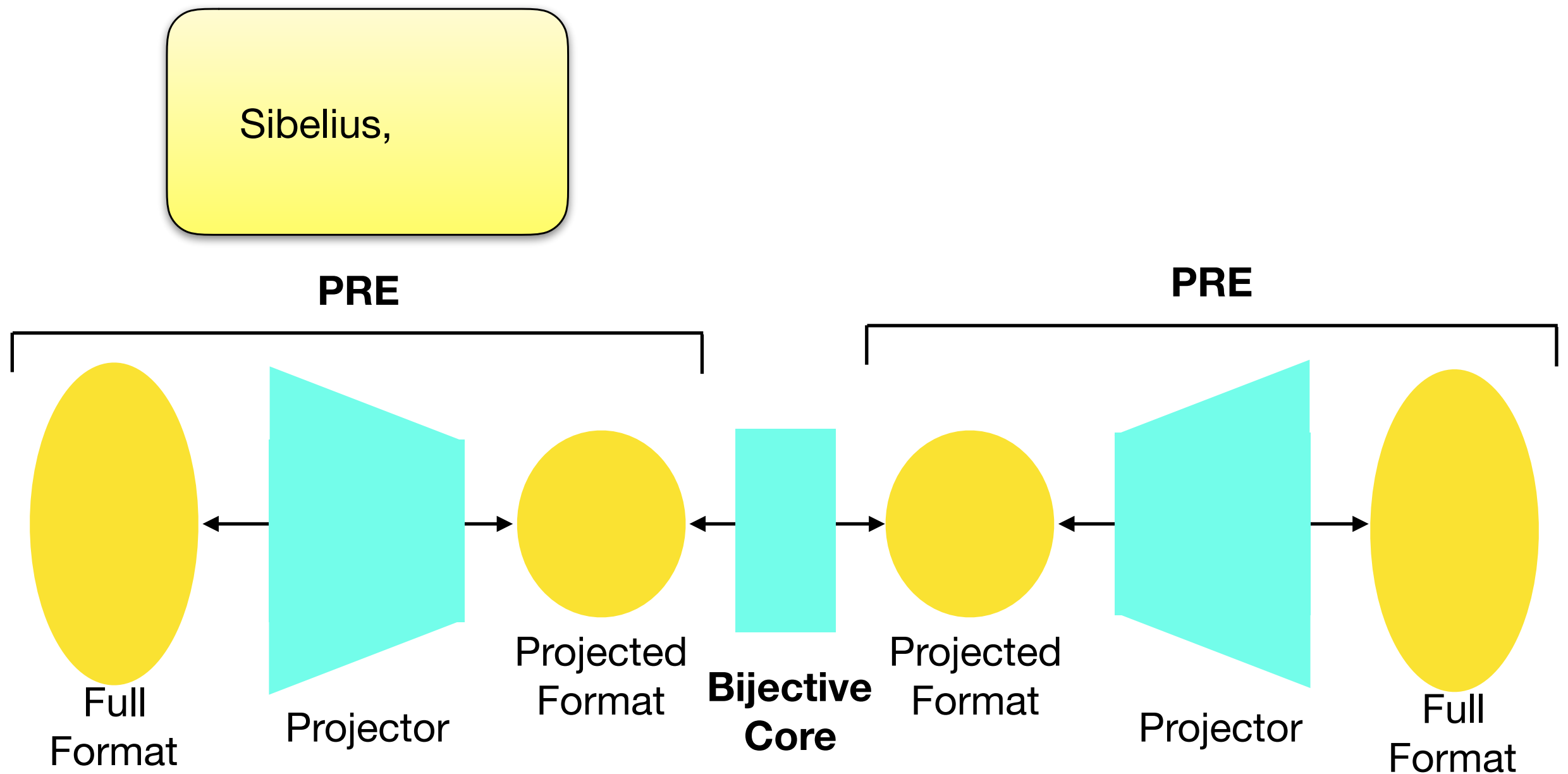


# Symmetric Lens Synthesis

Sibelius,

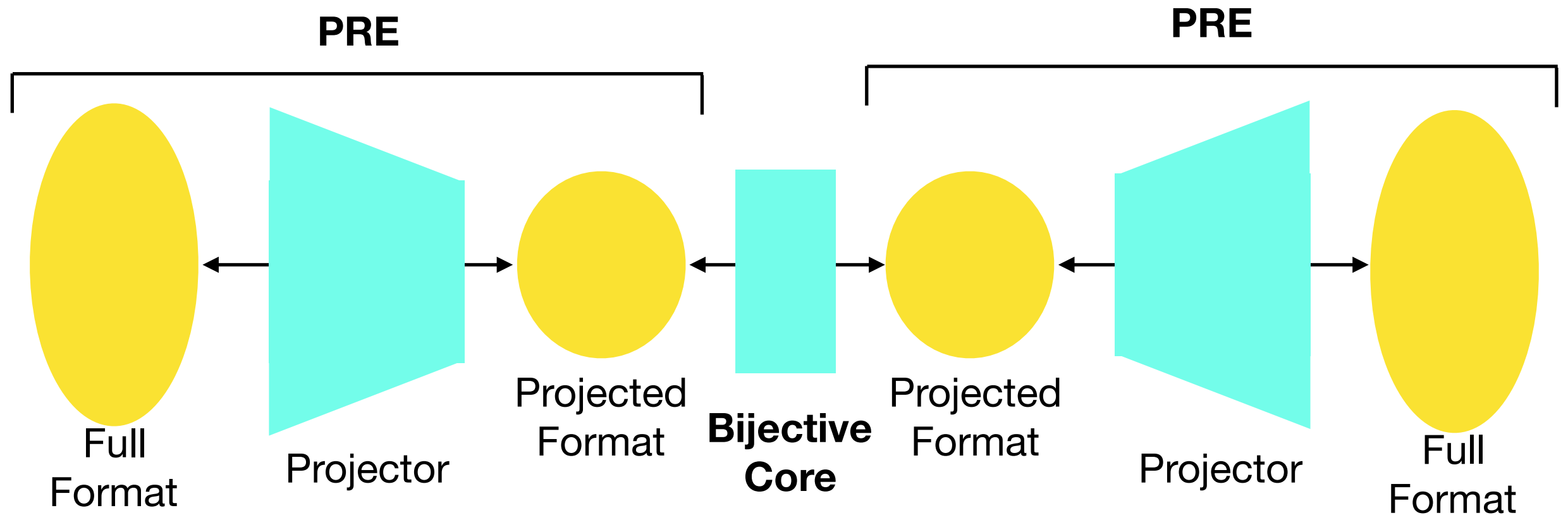


# Symmetric Lens Synthesis



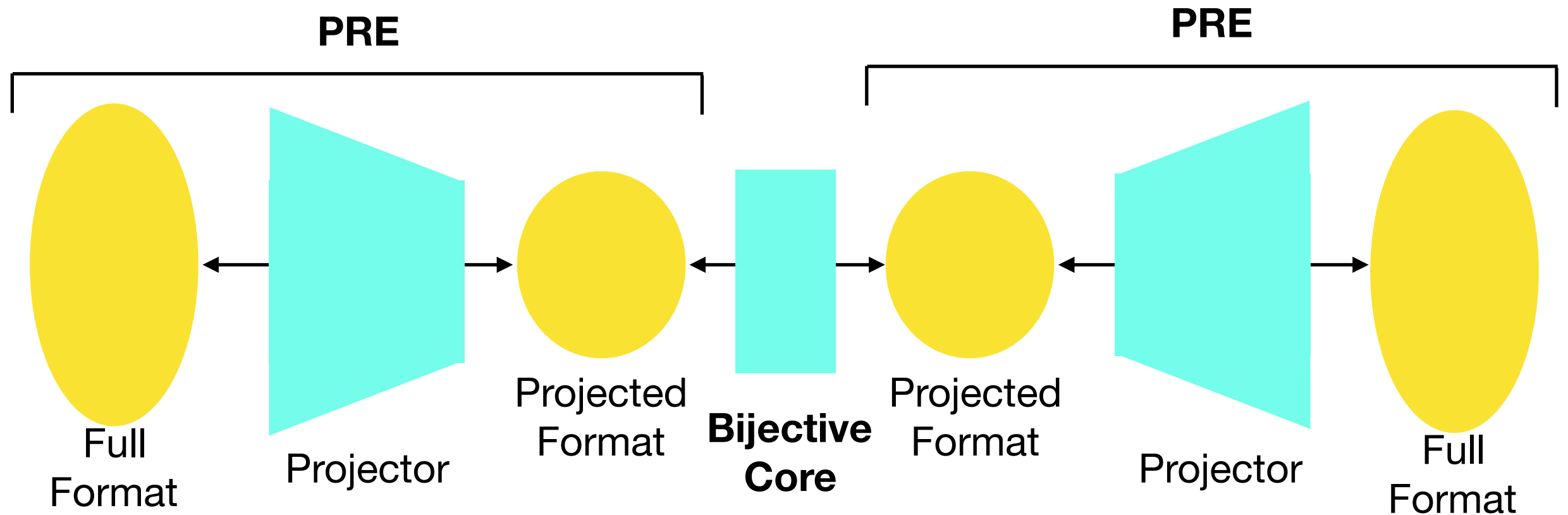
# Symmetric Lens Synthesis

Sibelius, 1865

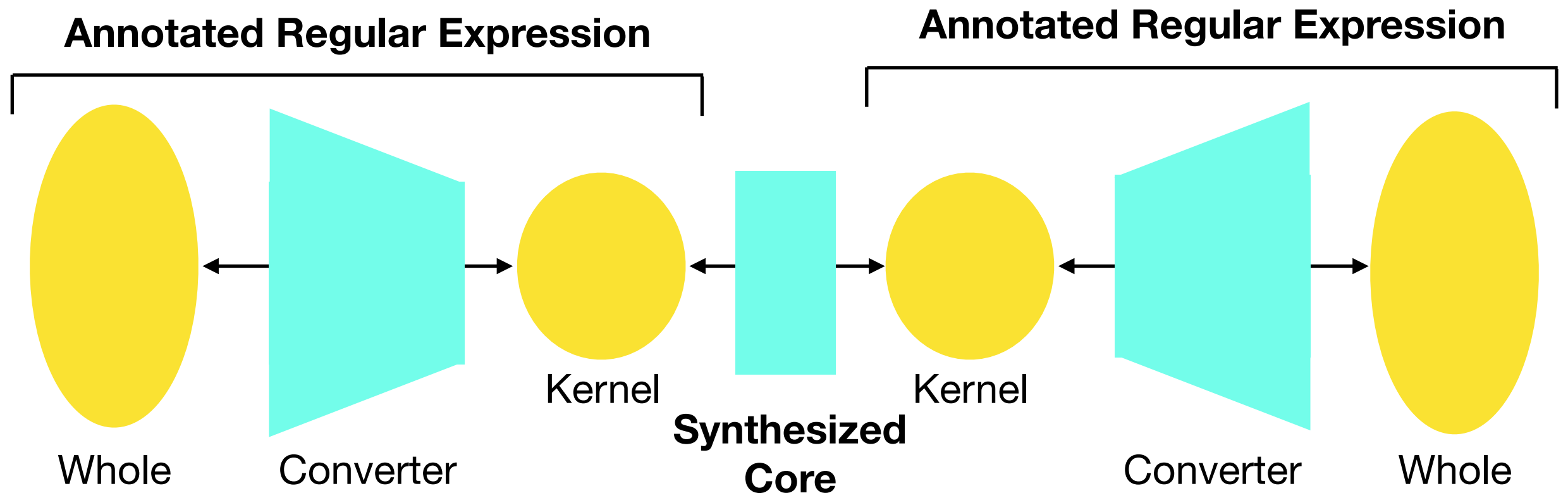


# Symmetric Lens Synthesis

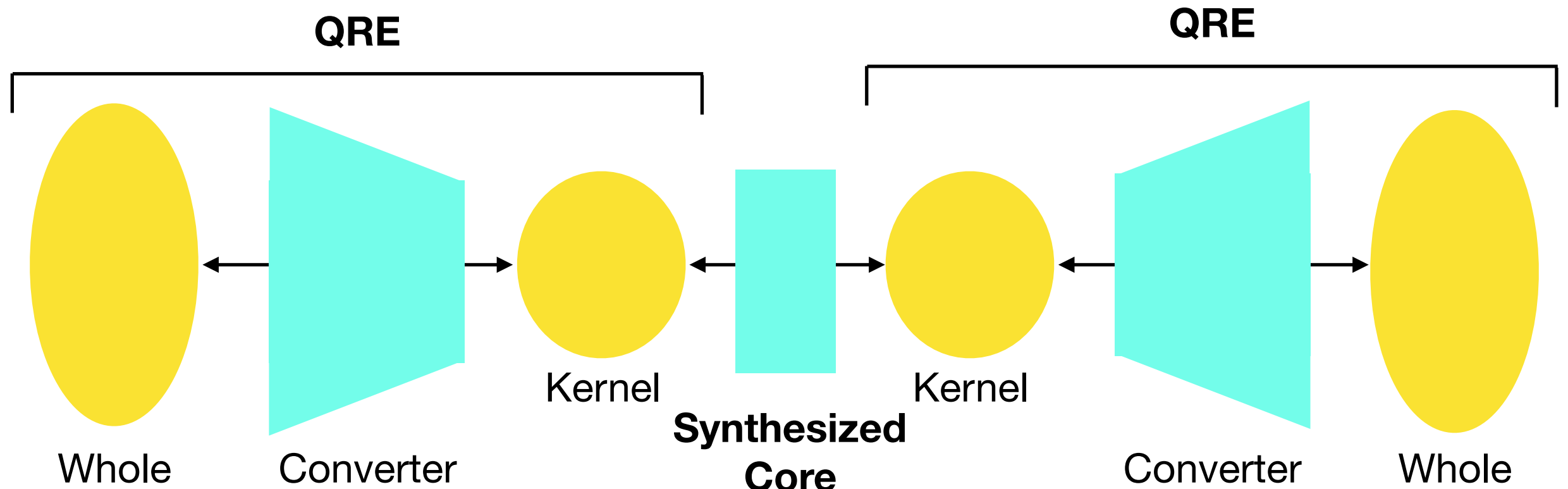
Sibelius, 1865



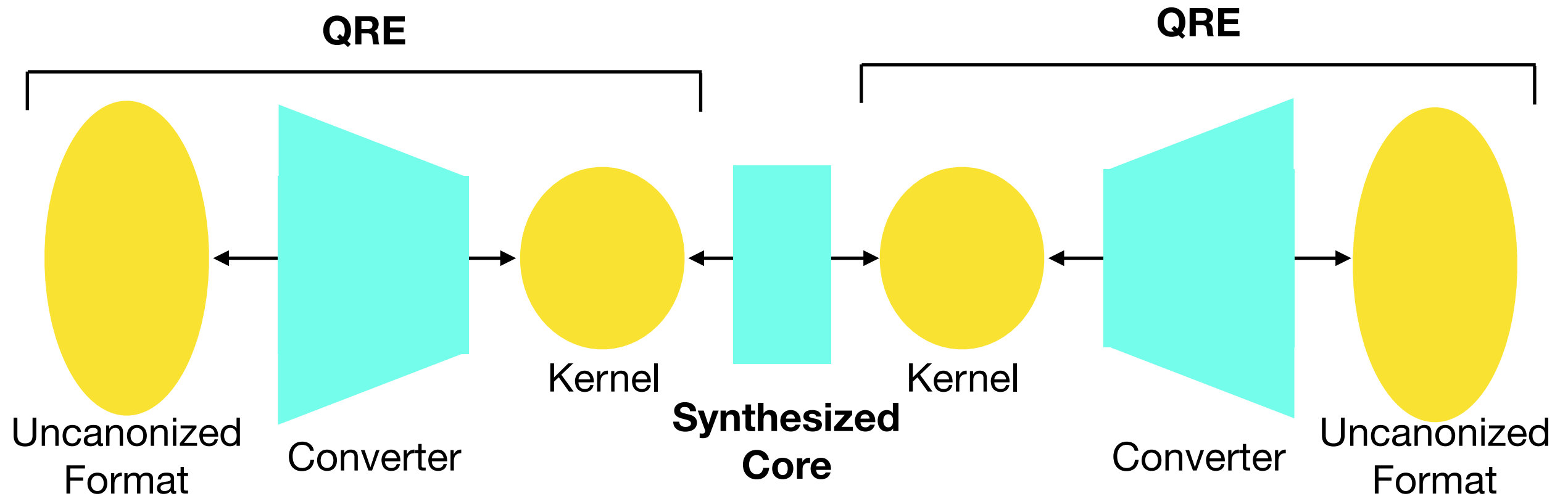
# A Framework for Lens Synthesis



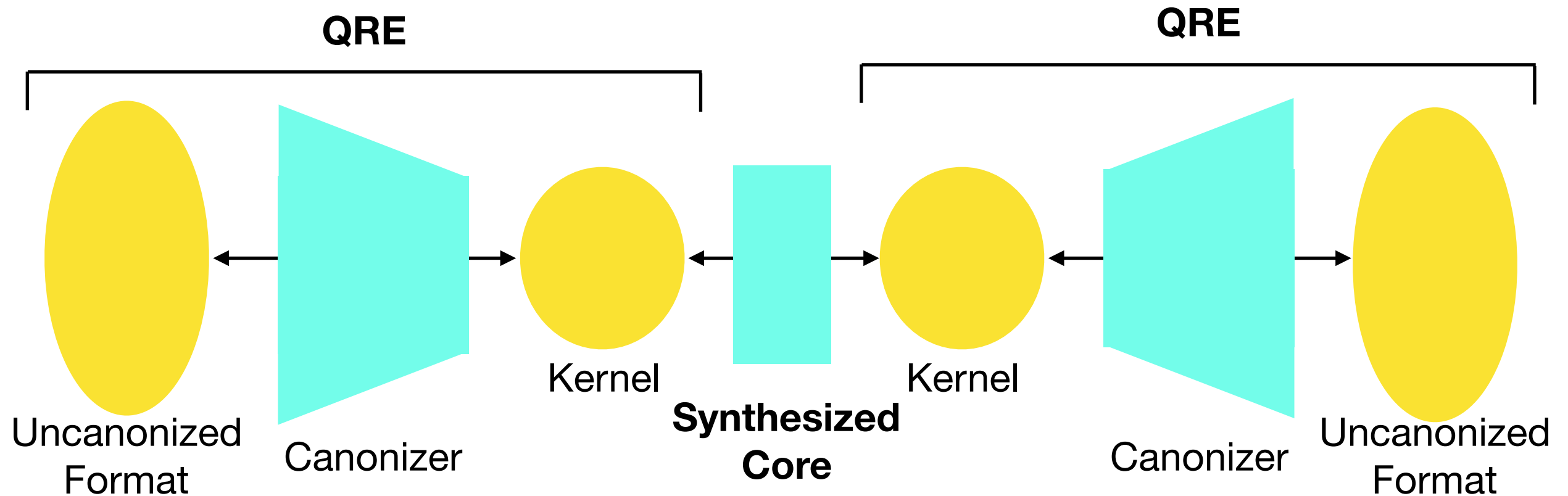
# Quotient Lens Synthesis



# Quotient Lens Synthesis

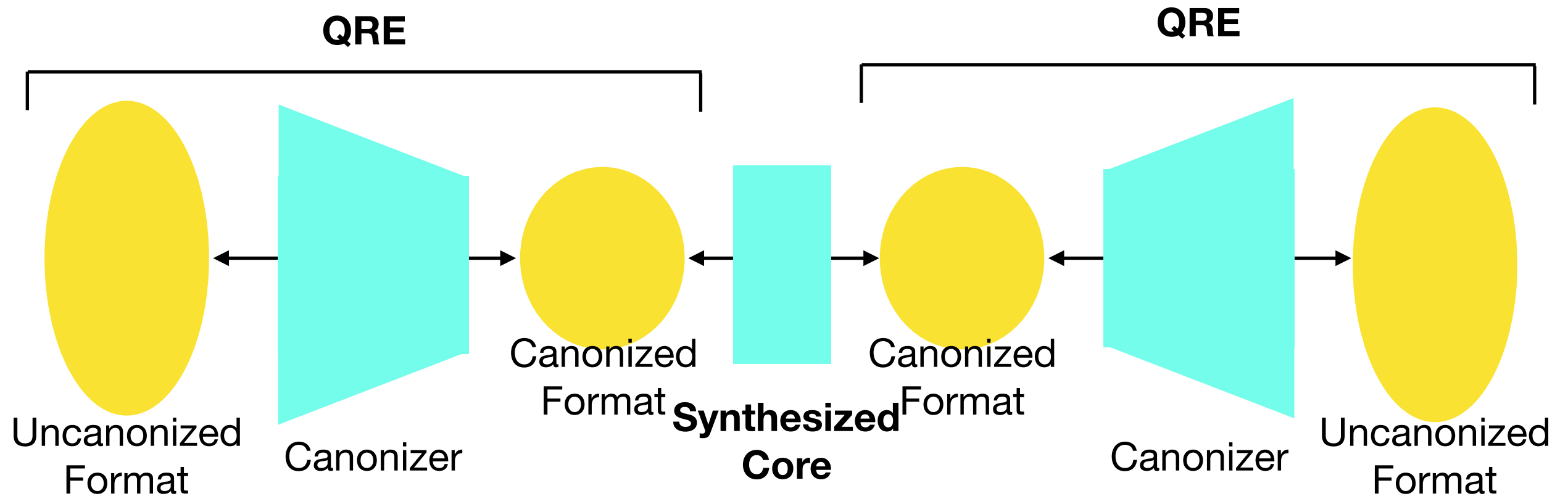


# Quotient Lens Synthesis

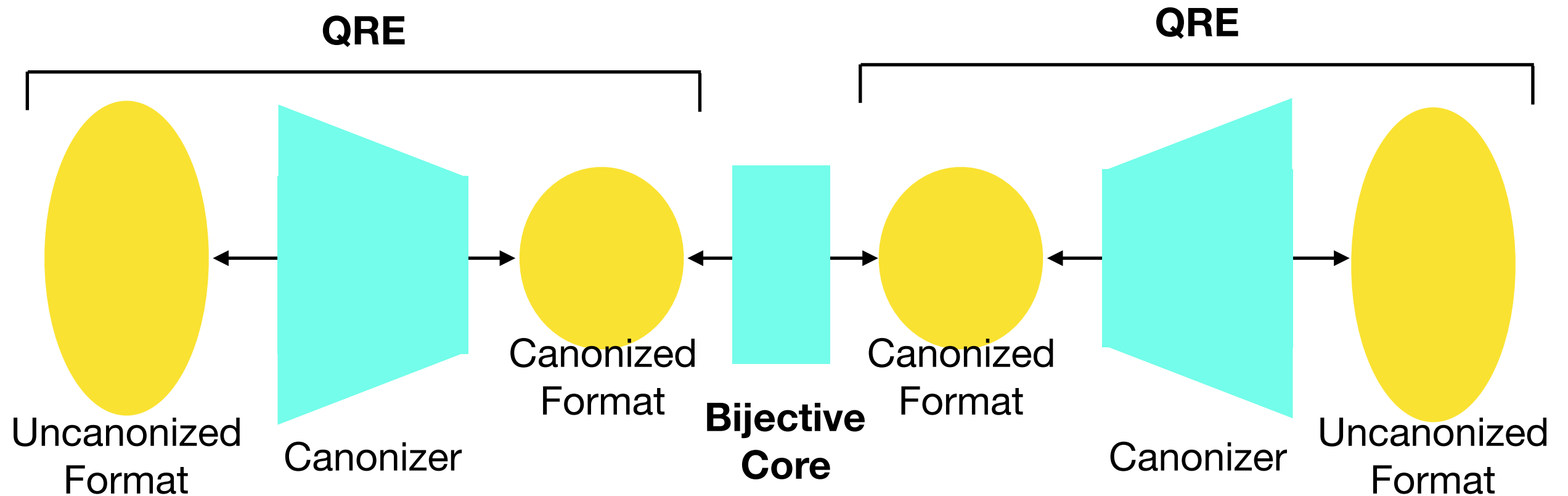




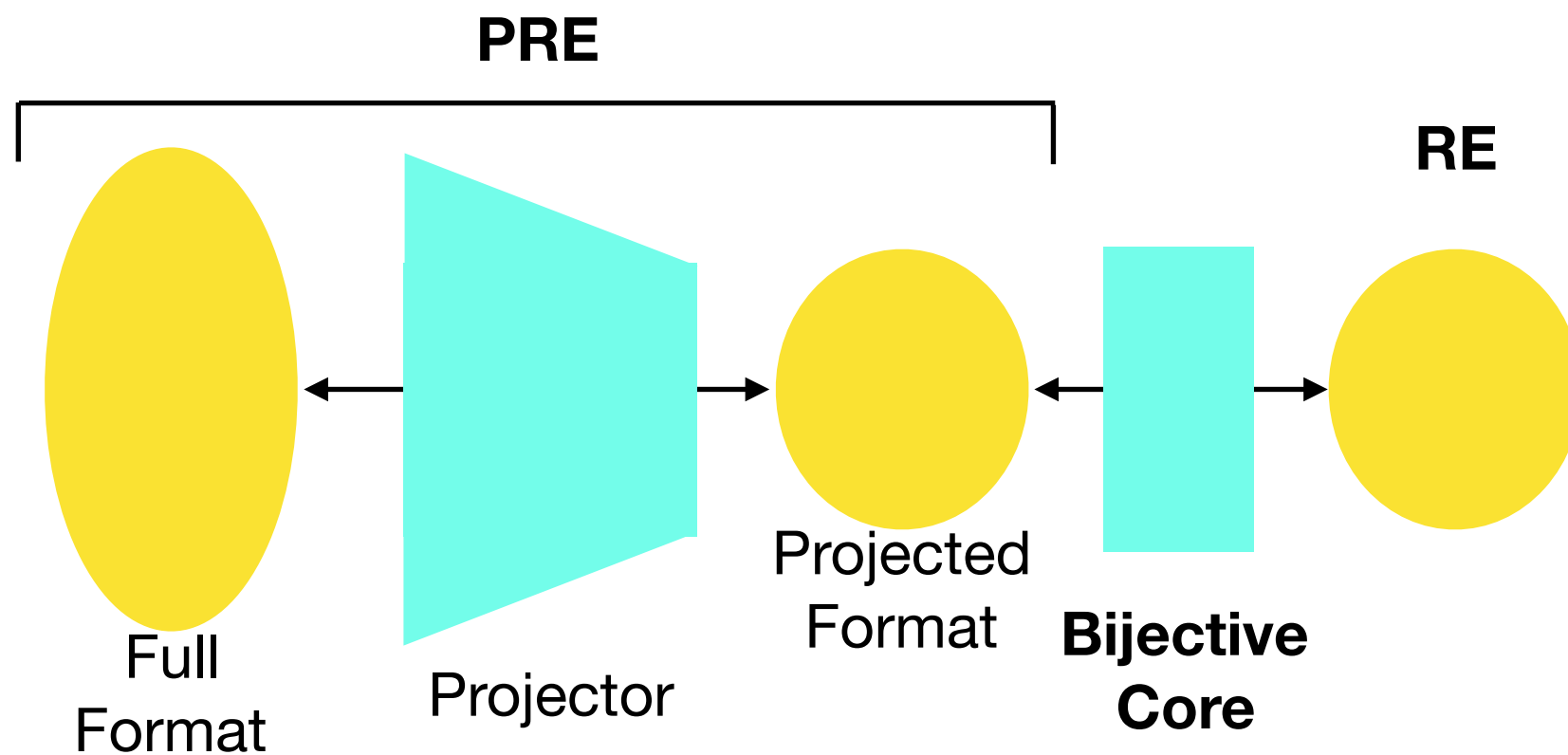
# Quotient Lens Synthesis



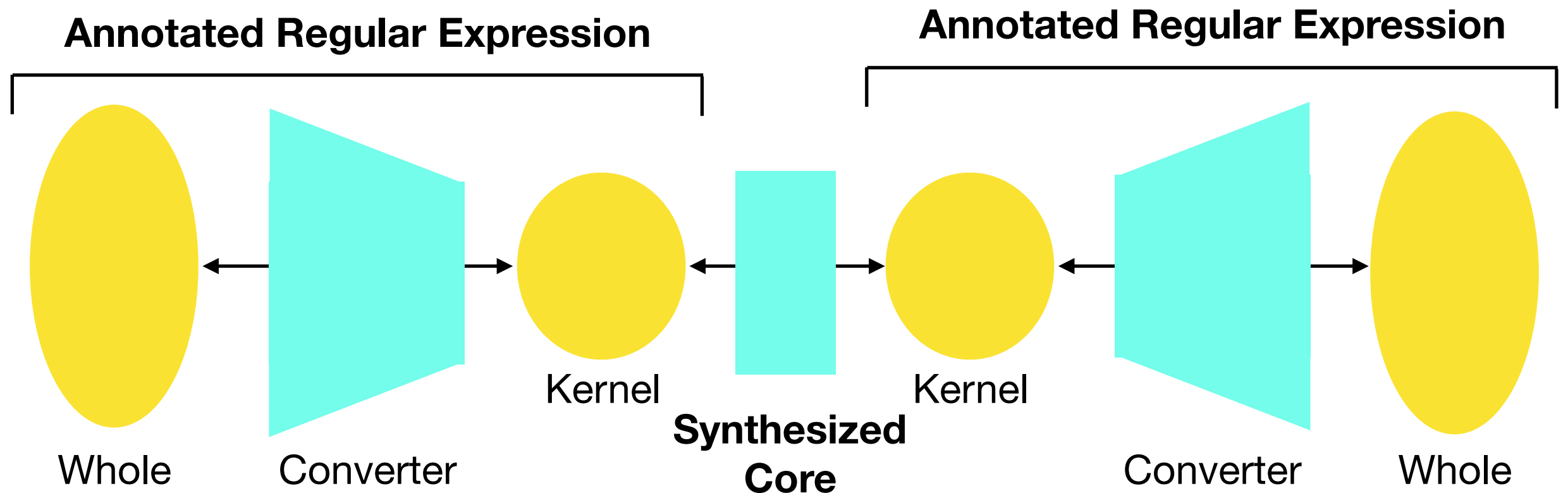
# Quotient Lens Synthesis



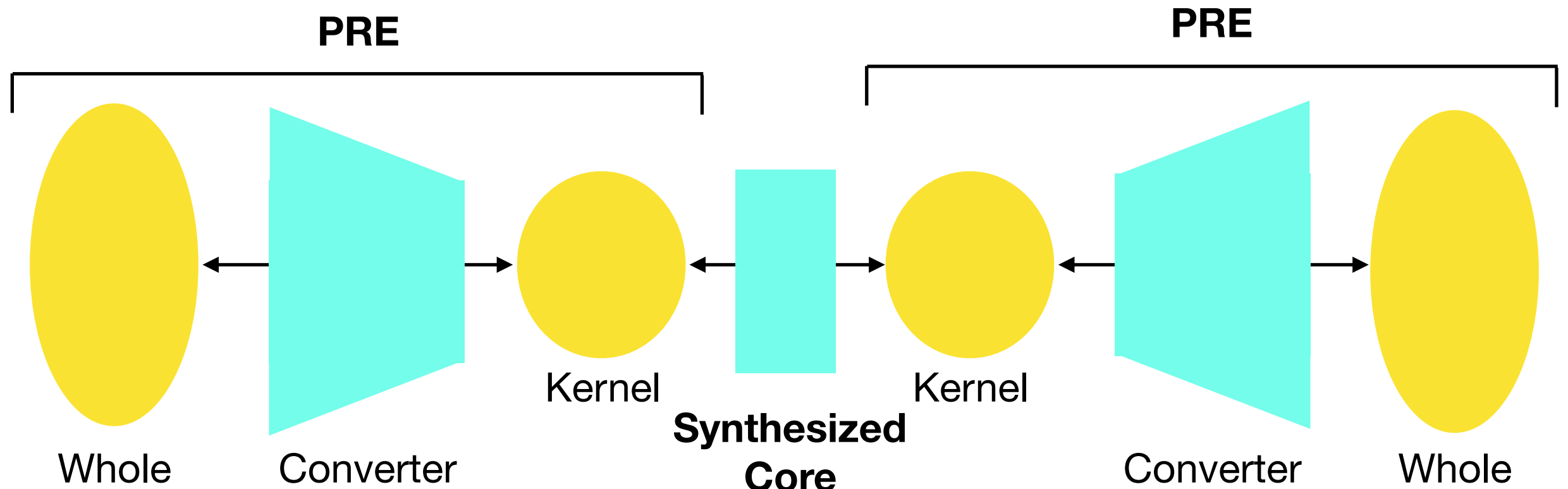
# Asymmetric Lens Synthesis



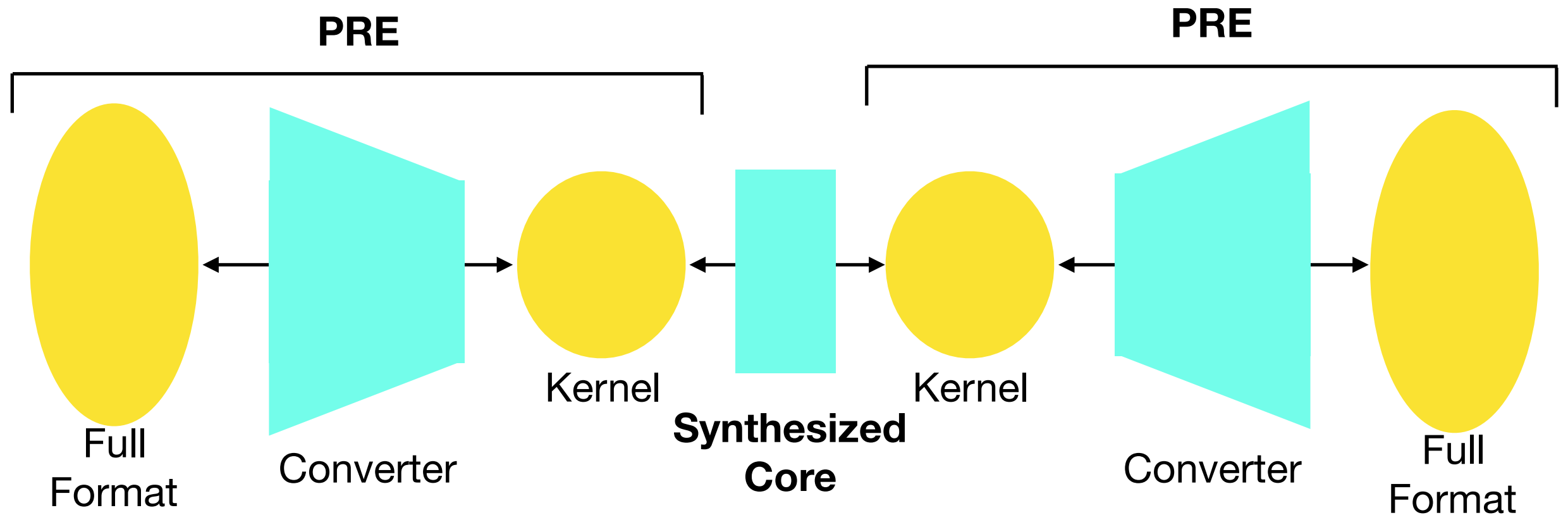
# A Framework for Lens Synthesis



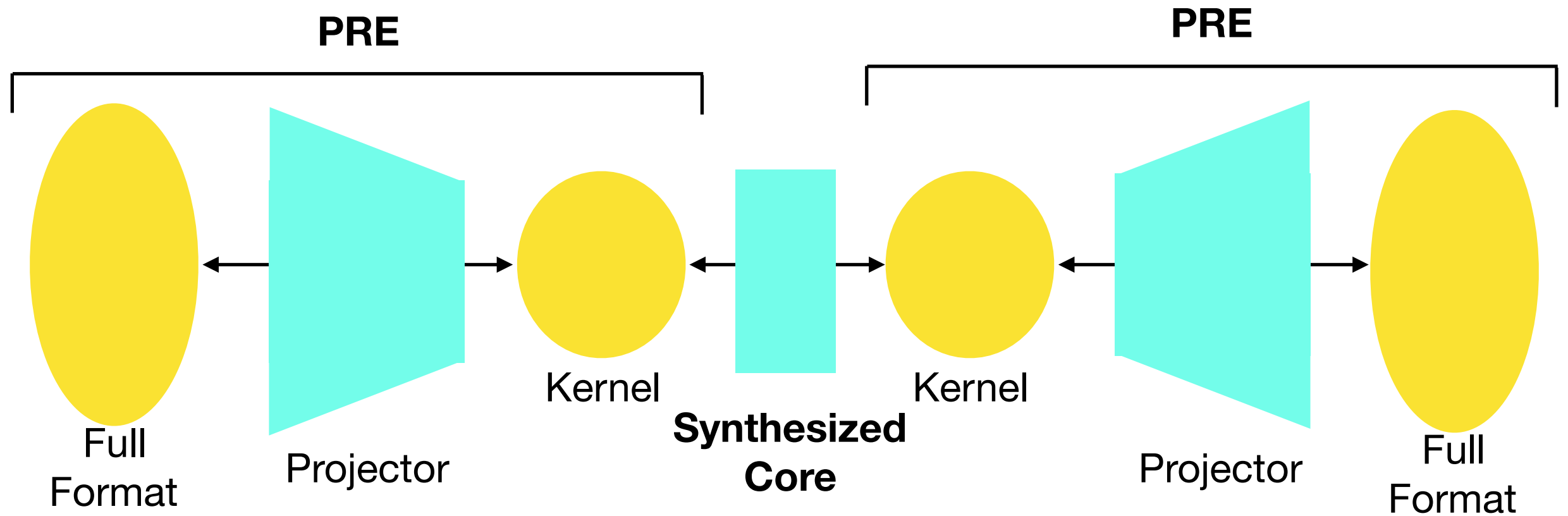
# Symmetric Lens Synthesis



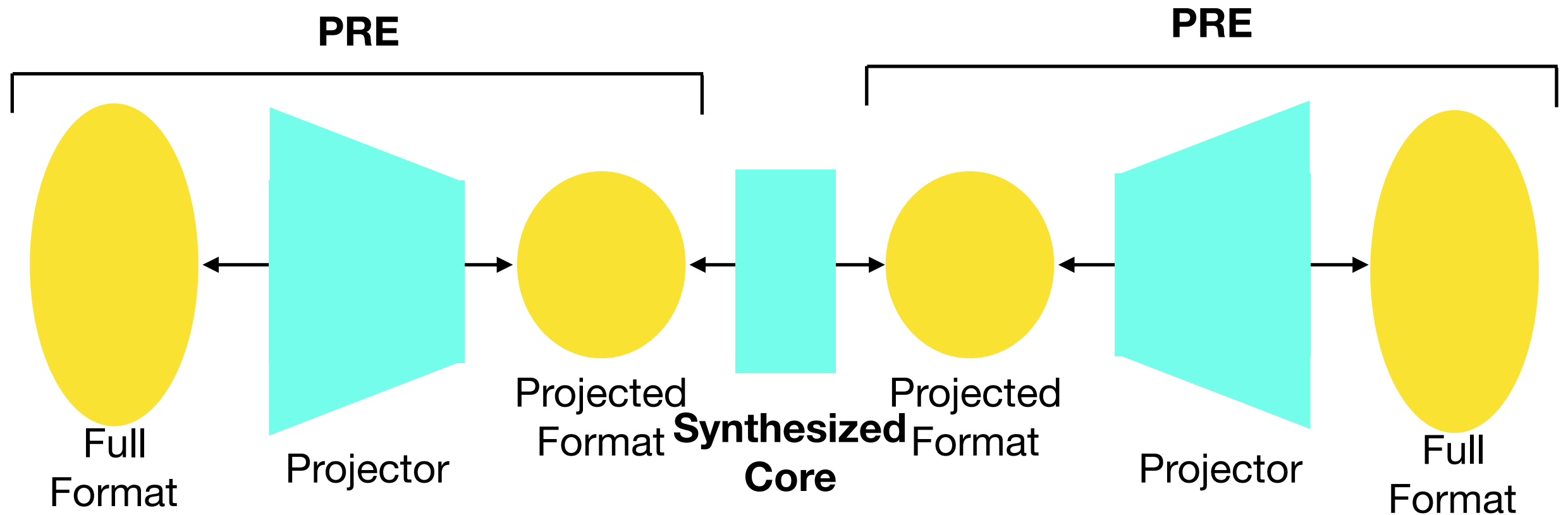
# Symmetric Lens Synthesis



# Symmetric Lens Synthesis

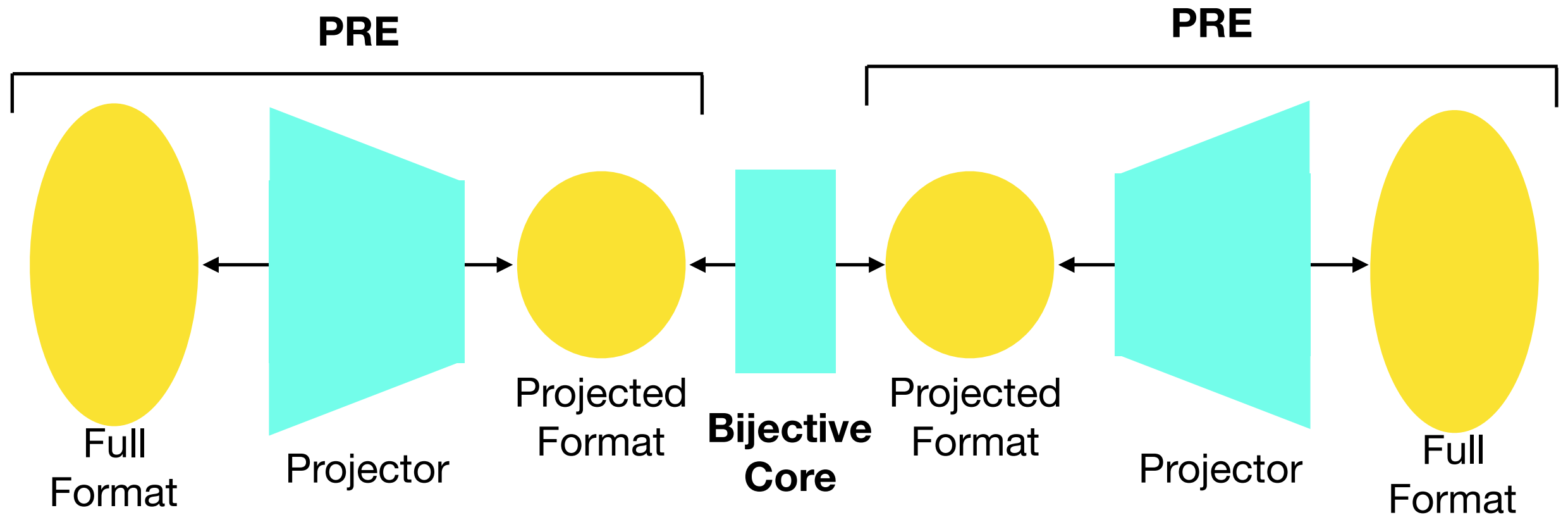


# Symmetric Lens Synthesis

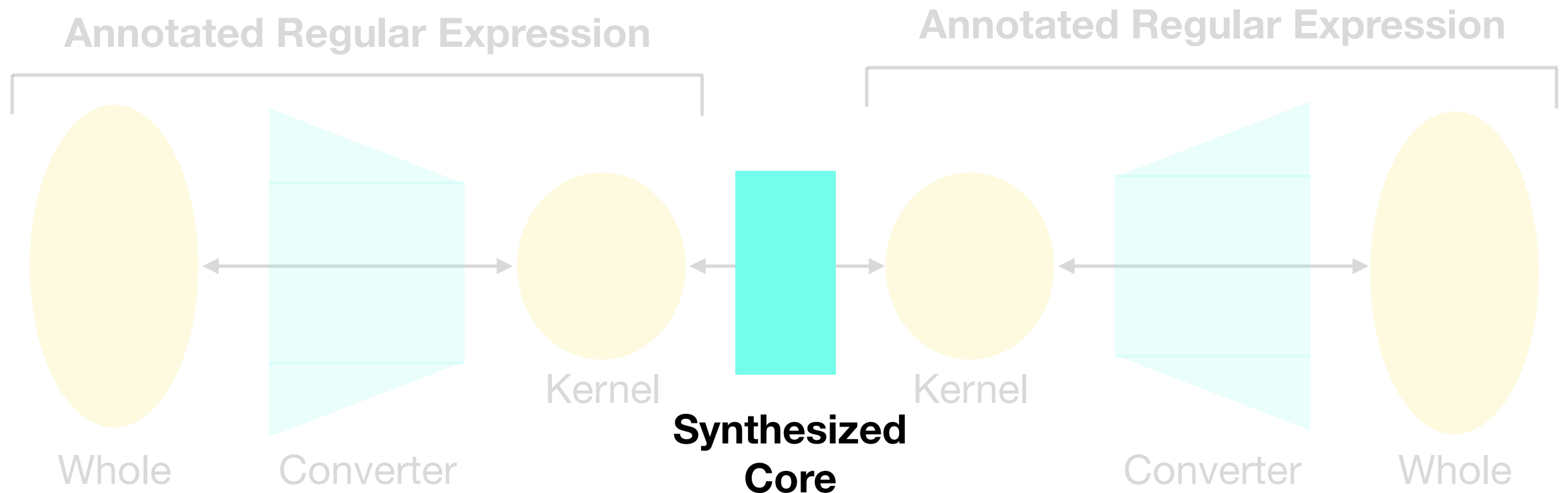




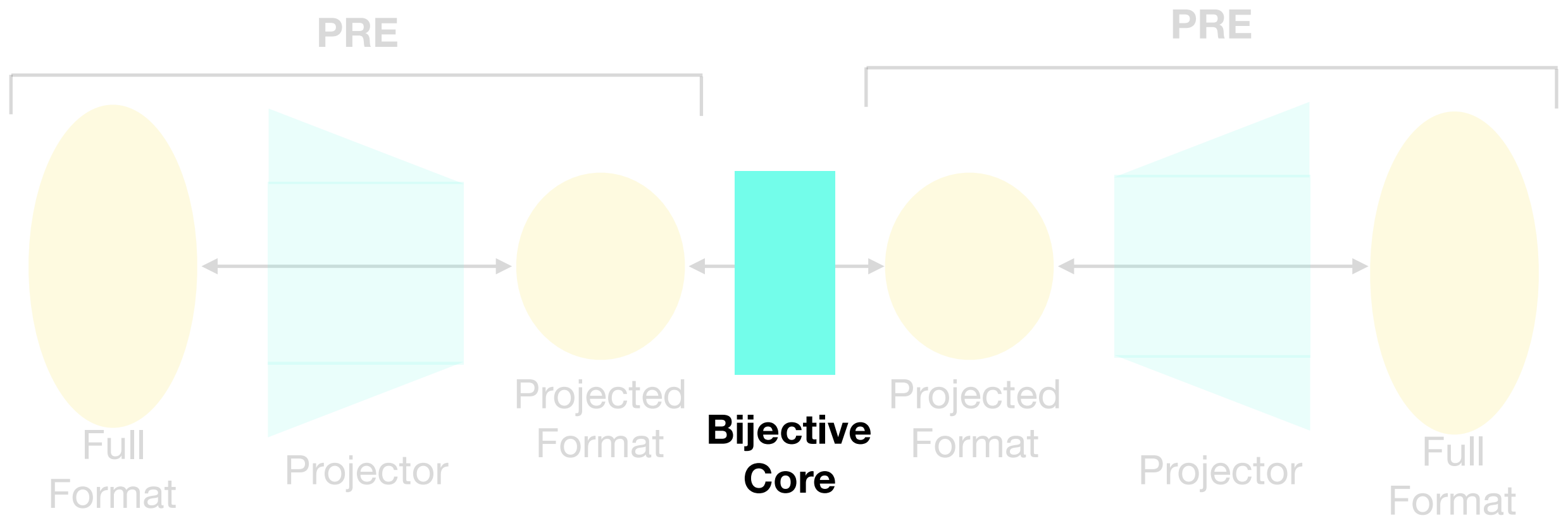
# Symmetric Lens Synthesis



# A Framework for Lens Synthesis

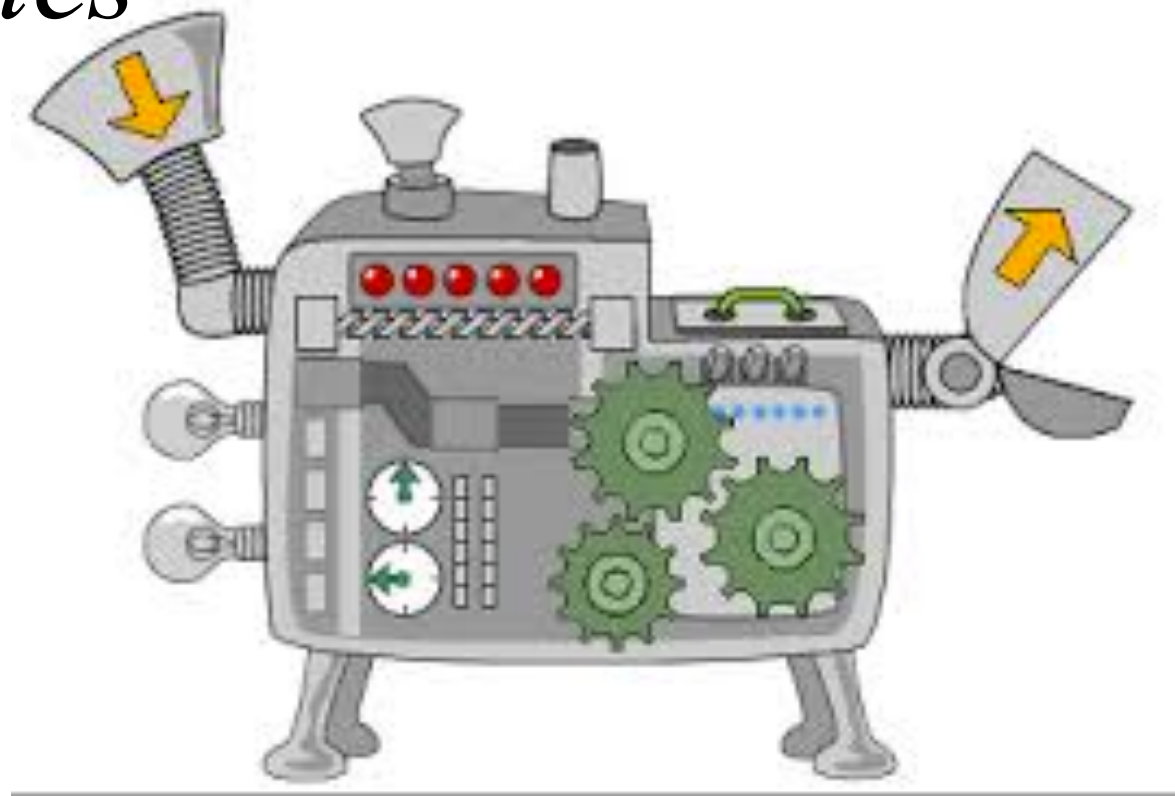


# \_ Lens Synthesis



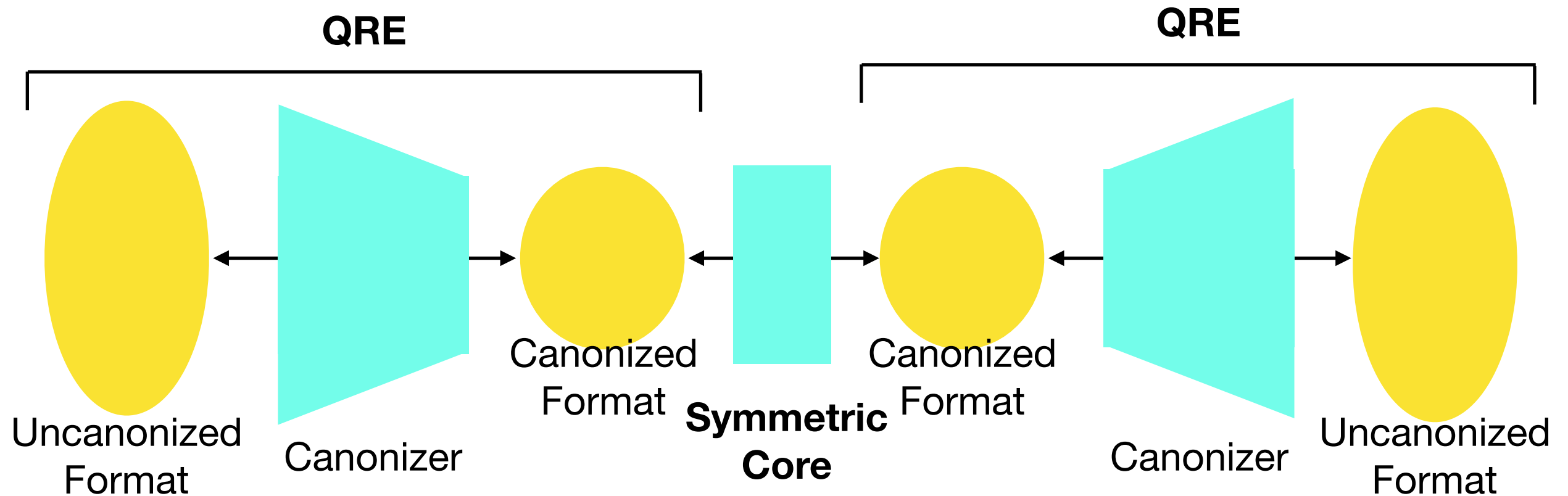
# Symmetric Synthesis

$R, S$   
*examples*

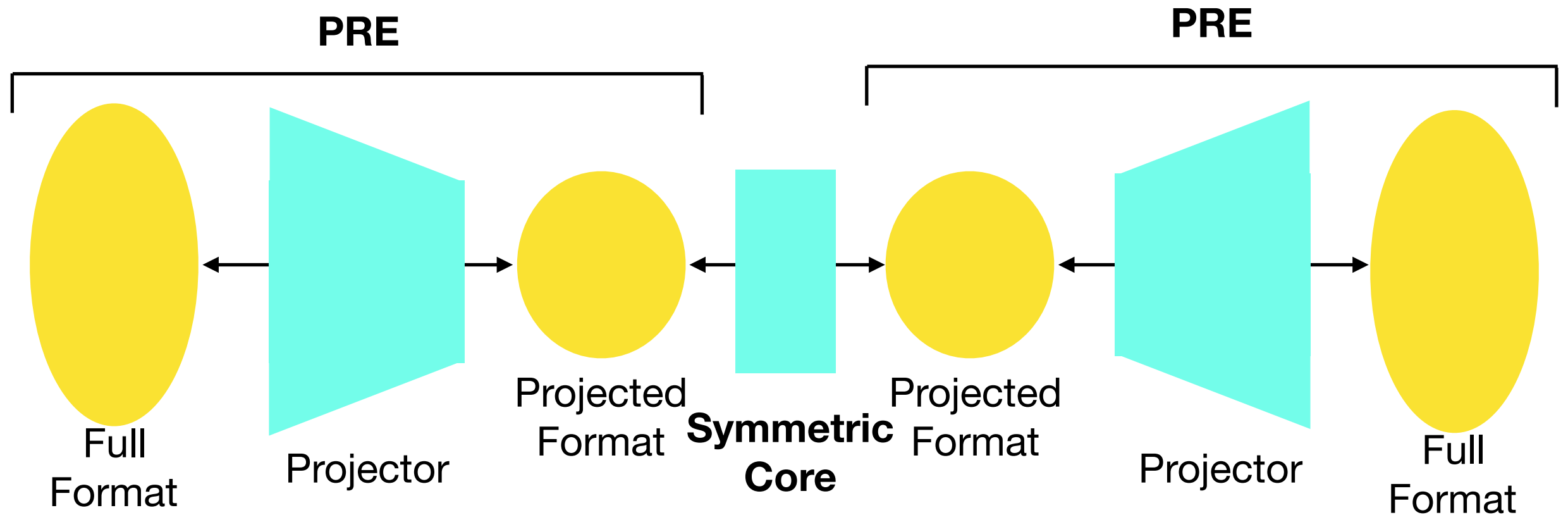


$$l : R \Leftrightarrow S$$

# Quotient Lens Synthesis



# Symmetric Lens Synthesis



# Summary

Framework for bidirectional program synthesis, utilizing type annotations and simpler synthesis subcomponents

If you want to power up your synthesis, annotate your input types to provide a kernel, a whole, and a converter

One inner synthesizer can work across multiple annotated input types

One class of annotated input types can work across multiple inner synthesizers