

Title: Mathematica - Lecture 3a

Date: Dec 10, 2012 09:00 AM

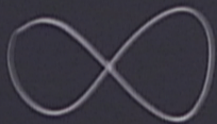
URL: <http://pirsa.org/12120020>

Abstract:

$$\mathcal{L} = \int d^d x \left(\partial \phi^2 + \frac{\lambda}{4!} \phi^4 \right)$$

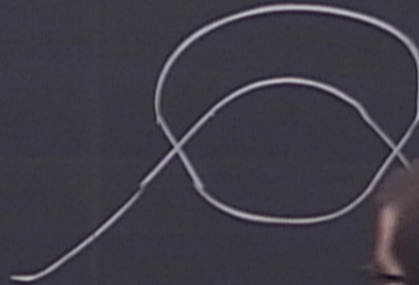


+

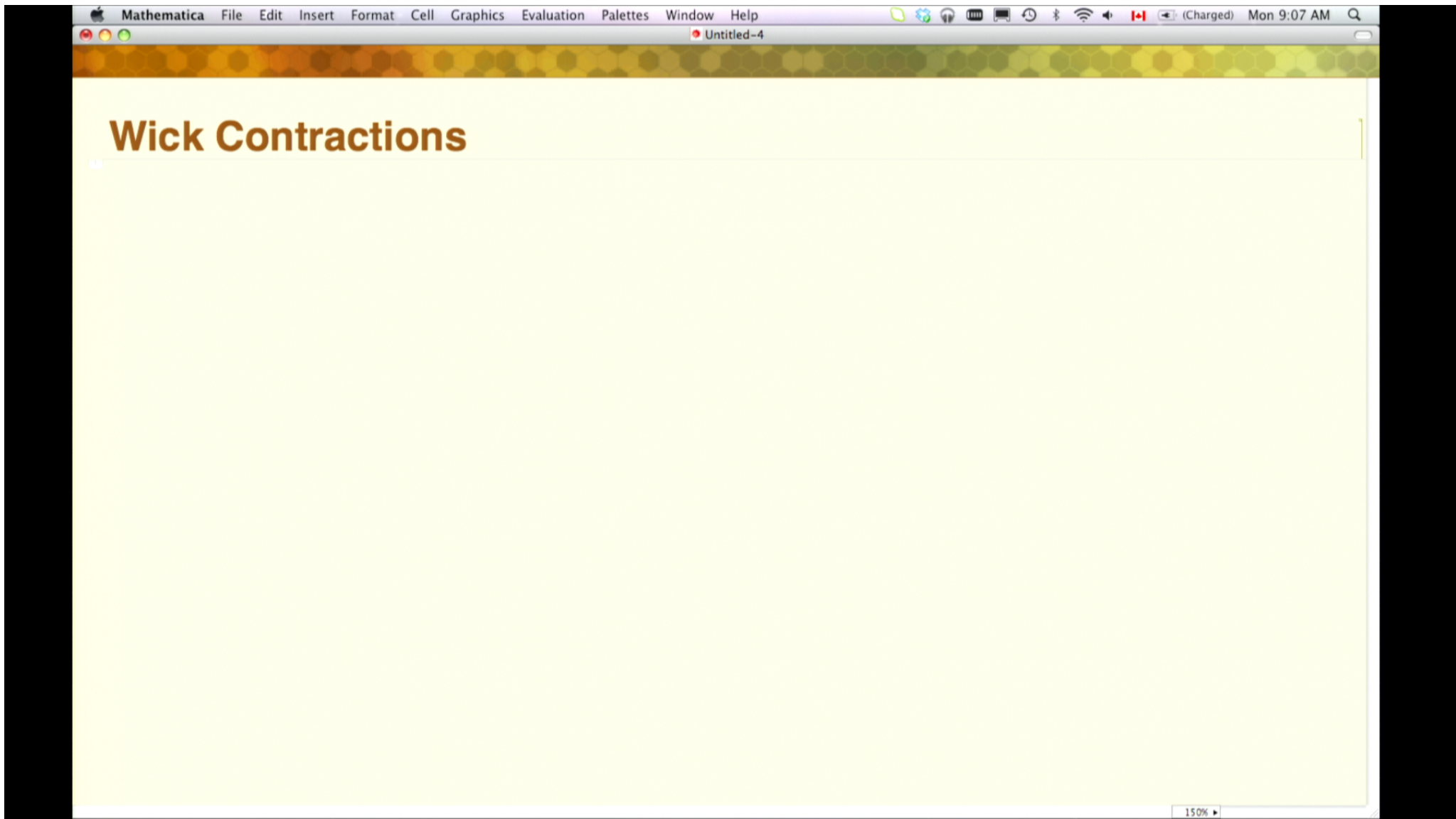


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...



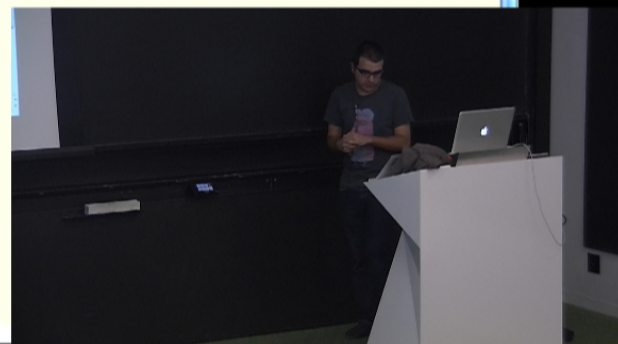
+ ...



Wick Contractions

$$\langle \phi(k_1) \phi(k_2) \phi(k_3) \rangle \text{ in } S = \int d^d x \left[(\partial \phi)^2 + \frac{\lambda}{n!} \phi^n + \dots \right]$$

- Function and Notation
- Computing the Wick contractions



Wick Contractions

$$\langle \phi(k_1) \phi(k_2) \phi(k_3) \rangle \text{ in } S = \int d^d x \left[(\partial \phi)^2 + \frac{\lambda}{n!} \phi^n + \dots \right]$$

- Function and Notation
- Computing the Wick contractions

```
towick =  $\phi[k[1]] \phi[k[2]]|$ 
```


Wick Contractions

$$\langle \phi(k_1) \phi(k_2) \phi(k_3) \rangle \text{ in } S = \int d^d x \left[(\partial \phi)^2 + \frac{\lambda}{n!} \phi^n + \dots \right]$$

- Function and Notation
- Computing the Wick contractions

In[62]:=

```
towick =  $\phi[k[1]] \phi[k[2]] \phi[k[\alpha[1]]] \phi[k[\alpha[2]]] \phi[k[\alpha[3]]] \phi[k[\alpha[4]]]$ 
```

Out[62]=

```
 $\phi[k_1] \phi[k_2] \phi[k_{\alpha[1]}] \phi[k_{\alpha[2]}] \phi[k_{\alpha[3]}] \phi[k_{\alpha[4]}]$ 
```

Wick Contractions

$$\langle \phi(k_1) \phi(k_2) \phi(k_3) \rangle \text{ in } S = \int d^d x \left[(\partial \phi)^2 + \frac{\lambda}{n!} \phi^n + \dots \right]$$

- Function and Notation
- Computing the Wick contractions

In[2]:=

```
towick =  $\phi[k1]$   $\phi[k2]$   $\phi[k[\alpha[1]]]$   $\phi[k[\alpha[2]]]$   $\phi[k[\alpha[3]]]$   $\phi[k[\alpha[4]]]$ 
```

Out[2]=

```
 $\phi[k1]$   $\phi[k2]$   $\phi[k[\alpha[1]]]$   $\phi[k[\alpha[2]]]$   $\phi[k[\alpha[3]]]$   $\phi[k[\alpha[4]]]$ 
```

In[1]:=

```
towick =  $\phi[k[1]]$   $\phi[k[2]]$   $\phi[k[\alpha[1]]]$   $\phi[k[\alpha[2]]]$   $\phi[k[\alpha[3]]]$   $\phi[k[\alpha[4]]]$ 
```

Out[1]=

```
 $\phi[k[1]]$   $\phi[k[2]]$   $\phi[k[\alpha[1]]]$   $\phi[k[\alpha[2]]]$   $\phi[k[\alpha[3]]]$   $\phi[k[\alpha[4]]]$ 
```


Wick Contractions

$$\langle \phi(k_1) \phi(k_2) \phi(k_3) \rangle \text{ in } S = \int d^d x \left[(\partial \phi)^2 + \frac{\lambda}{n!} \phi^n + \dots \right]$$

- Function and Notation
- Computing the Wick contractions

In[4]:=

k_1

Out[4]=

k_1

In[1]:=

`towick =  $\phi[k[1]] \phi[k[2]] \phi[k[\alpha[1]]] \phi[k[\alpha[2]]] \phi[k[\alpha[3]]] \phi[k[\alpha[4]]]$`

Out[1]=

$\phi[k[1]] \phi[k[2]] \phi[k[\alpha[1]]] \phi[k[\alpha[2]]] \phi[k[\alpha[3]]] \phi[k[\alpha[4]]]$

$$\langle \phi(k_1) \phi(k_2) \phi(k_3) \rangle \text{ in } S = \int d^d x \left[(\partial \phi)^2 + \frac{\lambda}{n!} \phi^n + \dots \right]$$

■ Function and Notation

■ Computing the Wick contractions

Notation Palette

- Notation [$\blacksquare$ $\leftrightarrow$ $\square$]
- Notation [$\blacksquare$ $\Rightarrow$ $\square$]
- Notation [$\blacksquare$ $\Leftarrow$ $\square$]
- Symbolize [$\blacksquare$]
- InfixNotation [$\blacksquare$, $\square$]
- AddInputAlias [$\square \rightarrow \square$]
- Full Notation Palette

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[  $k_{i_}$   $\Leftrightarrow$   $k[i_]$  ]
```

In[13]:=

```
 $k_1$  // FullForm
```

Out[13]//FullForm=

```
k[1]
```

In[14]:=

```
towick =  $\phi[k_1]$   $\phi[k_2]$   $\phi[k_{\alpha[1]}]$   $\phi[k_{\alpha[2]}]$   $\phi[k_{\alpha[3]}]$   $\phi[k_{\alpha[4]}]$ 
```

Out[14]=

```
 $\phi[k_1]$   $\phi[k_2]$   $\phi[k_{\alpha[1]}]$   $\phi[k_{\alpha[2]}]$   $\phi[k_{\alpha[3]}]$   $\phi[k_{\alpha[4]}]$ 
```

$$\langle \phi(k_1) \phi(k_2) \phi(k_3) \rangle \text{ in } S = \int d^d x \left[(\partial \phi)^2 + \frac{\lambda}{n!} \phi^n + \dots \right]$$

■ Function and Notation

■ Computing the Wick contractions

Notation Palette

- Notation [$\blacksquare$ $\Leftrightarrow$ $\square$]
- Notation [$\blacksquare$ $\Rightarrow$ $\square$]
- Notation [$\blacksquare$ $\Leftarrow$ $\square$]
- Symbolize [$\blacksquare$]
- InfixNotation [$\blacksquare$, $\square$]
- AddInputAlias [$\square \rightarrow \square$]
- Full Notation Palette

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[ k_i_  $\Leftrightarrow$  k[i_] ]
```

In[13]:=

```
k_1 // FullForm
```

Out[13]//FullForm=

```
k[1]
```

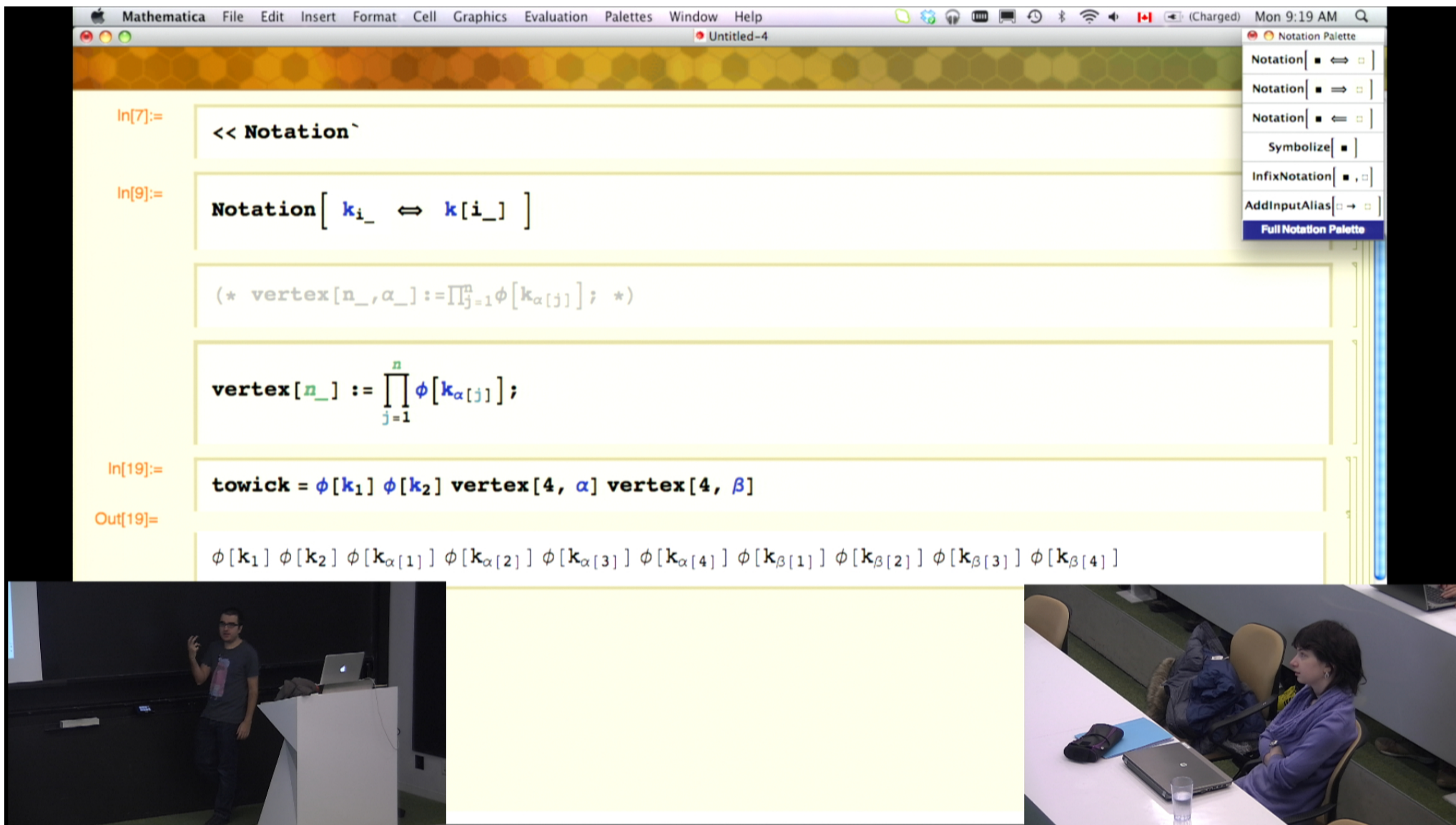
```
vertex[n_] :=  $\prod_{j=1}^n \phi[k_{\alpha[j]}]$ 
```

In[14]:=

```
towick =  $\phi[k_1] \phi[k_2] \phi[k_{\alpha[1]}] \phi[k_{\alpha[2]}] \phi[k_{\alpha[3]}] \phi[k_{\alpha[4]}]$ 
```

Out[14]=

```
 $\phi[k_1] \phi[k_2] \phi[k_{\alpha[1]}] \phi[k_{\alpha[2]}] \phi[k_{\alpha[3]}] \phi[k_{\alpha[4]}]$ 
```

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Untitled-4

Mon 9:19 AM

Notation Palette

Notation $\Leftarrow$

Notation $\Rightarrow$

Notation $\Leftrightarrow$

Symbolize

InfixNotation $\square, \square$

AddInputAlias $\square \rightarrow \square$

Full Notation Palette

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[ ki  $\Leftrightarrow$  k[i] ]
```

(* vertex[n_, α_] := $\prod_{j=1}^n \phi[k_{\alpha[j]}]$; *)

```
vertex[n_] :=  $\prod_{j=1}^n \phi[k_{\alpha[j]}]$ ;
```

In[19]:=

```
towick =  $\phi[k_1] \phi[k_2]$  vertex[4, α] vertex[4, β]
```

Out[19]=

```
 $\phi[k_1] \phi[k_2] \phi[k_{\alpha[1]}] \phi[k_{\alpha[2]}] \phi[k_{\alpha[3]}] \phi[k_{\alpha[4]}] \phi[k_{\beta[1]}] \phi[k_{\beta[2]}] \phi[k_{\beta[3]}] \phi[k_{\beta[4]}]$ 
```


Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

Mon 9:19 AM

Notation Palette

Notation $\Leftarrow$

Notation $\Rightarrow$

Notation $\Leftrightarrow$

Symbolize

InfixNotation

AddInputAlias

Full Notation Palette

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[ ki  $\Leftrightarrow$  k[i_] ]
```

```
(* vertex[n_,  $\alpha$ _] :=  $\prod_{j=1}^n \phi[k_{\alpha[j]}]$ ; *)
```

In[20]:=

```
Unique[ $\alpha$ ]
```

Out[20]=

```
 $\alpha$ $621
```

In[21]:=

```
Unique[ $\alpha$ ]
```

Out[21]=

```
 $\alpha$ $623
```

```
vertex[n_] := Block[{lette $\prod_{j=1}^n \phi[k_{\alpha[j]}]$ ];
```

In[19]:=

```
towick =  $\phi[k_1] \phi[k_2]$  vertex[4,  $\alpha$ ] vertex[4,  $\beta$ ]
```

200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

Notation Palette

Notation $\square \leftrightarrow \square$

Notation $\square \Rightarrow \square$

Notation $\square \Leftarrow \square$

Symbolize $\square$

InfixNotation $\square, \square$

AddInputAlias $\square \rightarrow \square$

Full Notation Palette

In[9]:=

```
Notation[  $k_{i_}$   $\Leftrightarrow$   $k[i_]$  ]
```

(* vertex[n_, α] := $\prod_{j=1}^n \phi[k_{\alpha[j]}]$; *)

In[20]:=

```
Unique[ $\alpha$ ]
```

Out[20]=

$\alpha\$621$

In[21]:=

```
Unique[ $\alpha$ ]
```

Out[21]=

$\alpha\$623$

In[22]:=

```
vertex[n_] := Block[{letter = Unique[ $\alpha$ ]},  $\prod_{j=1}^n \phi[k_{\text{letter}[j]}]$ ]
```

In[23]:=

```
vertex[4]
```

Out[23]=

$\phi[k_{\alpha\$626[1]}] \phi[k_{\alpha\$626[2]}] \phi[k_{\alpha\$626[3]}] \phi[k_{\alpha\$626[4]}]$

200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

Notation Palette

Notation $\Leftarrow$

Notation $\Rightarrow$

Notation $\Leftrightarrow$

Symbolize

InfixNotation $\square, \square$

AddInputAlias $\square \rightarrow \square$

Full Notation Palette

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[  $k_{i_}$   $\Leftrightarrow$   $k[i_]$  ]
```

(* vertex[n_, $\alpha_$] := $\prod_{j=1}^n \phi[k_{\alpha[j]}]$; *)

In[22]:=

```
vertex[n_] := Block[{letter = Unique[ $\alpha$ ]},  $\prod_{j=1}^n \phi[k_{\text{letter}[j]}]$ ]
```

In[25]:=

```
towick =  $\phi[k_1] \phi[k_2]$  vertex[4] vertex[4]
```

Out[25]=

```
 $\phi[k_1] \phi[k_2] \phi[k_{\alpha\$629[1]}] \phi[k_{\alpha\$629[2]}] \phi[k_{\alpha\$629[3]}]$   

 $\phi[k_{\alpha\$629[4]}] \phi[k_{\alpha\$630[1]}] \phi[k_{\alpha\$630[2]}] \phi[k_{\alpha\$630[3]}] \phi[k_{\alpha\$630[4]}]$ 
```

200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

Mon 9:22 AM

Notation Palette

Notation $\Leftarrow$

Notation $\Rightarrow$

Notation $\Leftrightarrow$

Symbolize

InfixNotation

AddInputAlias

Full Notation Palette

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[ k_i_  $\Leftrightarrow$  k[i_] ]
```

(* vertex[n_, α _] := $\prod_{j=1}^n \phi[k_{\alpha[j]}]$; *)

```
vertex[n_] := Block[{letter = Unique[ $\alpha$ ]},  $\prod_{j=1}^n \phi[k_{\text{letter}[j]}]$ ]
```

In[28]:=

```
towick =  $\phi[k_1] \phi[k_2]$  vertex[4] vertex[4]
EvenQ@Count[towick,  $\phi[_]$ ]
```

Out[28]=

```
 $\phi[k_1] \phi[k_2] \phi[k_{\alpha\$635[1]}] \phi[k_{\alpha\$635[2]}] \phi[k_{\alpha\$635[3]}]$ 
 $\phi[k_{\alpha\$635[4]}] \phi[k_{\alpha\$636[1]}] \phi[k_{\alpha\$636[2]}] \phi[k_{\alpha\$636[3]}] \phi[k_{\alpha\$636[4]}]$ 
```

Out[29]=

```
True
```

200%

$$\langle \phi(k_1) \phi(k_2) \phi(k_3) \rangle \text{ in } S = \int d^d x \left[(\partial \phi)^2 + \frac{\lambda}{n!} \phi^n + \dots \right]$$

■ Function and Notation

■ Computing the Wick contractions

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[ ki_ ⇔ k[i_] ]
```

```
(* vertex[n_, α_] := ∏j=1n φ[kα[j]]; *)
```

```
vertex[n_] := Block[{letter = Unique[α]}, ∏j=1n φ[kletter[j]]]
```

In[30]:=

```
towick = φ[k1] φ[k2] vertex[4] vertex[4];
EvenQ@Count[towick, φ[_]]
```

Out[31]=

```
True
```

$$\langle \phi(k_1) \phi(k_2) \phi(k_3) \rangle \text{ in } S = \int d^d x \left[(\partial \phi)^2 + \frac{\lambda}{n!} \phi^n + \dots \right]$$

■ Function and Notation

In[34]:=

```
List @@ towick
```

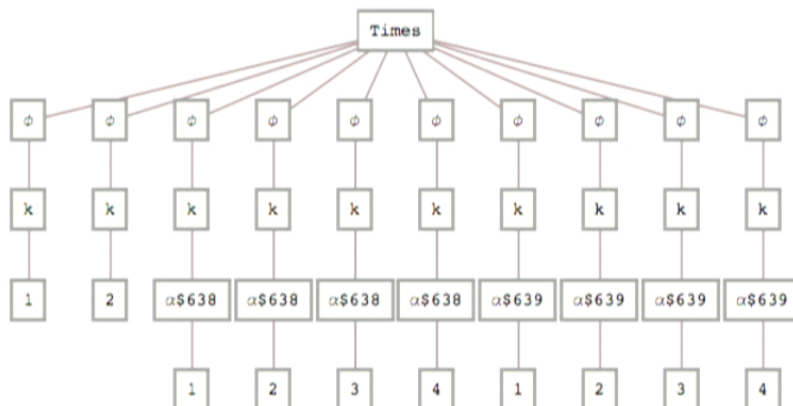
Out[34]=

```
{phi[k1], phi[k2], phi[k_alpha$638[1]], phi[k_alpha$638[2]], phi[k_alpha$638[3]],  
phi[k_alpha$638[4]], phi[k_alpha$639[1]], phi[k_alpha$639[2]], phi[k_alpha$639[3]], phi[k_alpha$639[4]]}
```

In[33]:=

```
towick // TreeForm
```

Out[33]//TreeForm=



■ Function and Notation

In[35]:=

```
List @@ towick // TreeForm
```

```
wick[X_Times] := Block[{list = List @@ X}, {list[[1]], list[[j]] :>>}]
```

■ Computing the Wick contractions

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[ $k_{i_}$   $\Leftrightarrow$   $k[i_]$ ]
```

```
(* vertex[n_,  $\alpha_$ ] :=  $\prod_{j=1}^n \phi[k_{\alpha[j]}]$ ; *)
```

```
vertex[n_] := Block[{letter = Unique[ $\alpha$ ]},  $\prod_{j=1}^n \phi[k_{\text{letter}[j]}]$ ]
```

In[30]:=

```
towick =  $\phi[k_1] \phi[k_2]$  vertex[4] vertex[4];  
EvenQ@Count[towick,  $\phi[_]$ ]
```

Out[31]=

Notation Palette

- Notation $\blacksquare \Leftrightarrow \square$
- Notation $\blacksquare \Rightarrow \square$
- Notation $\blacksquare \Leftarrow \square$
- Symbolize $\blacksquare$
- InfixNotation $\blacksquare, \square$
- AddInputAlias $\square \rightarrow \square$
- Full Notation Palette

■ Function and Notation

In[35]:=

```
List @@ towick // TreeForm
```

```
wick[X_Times] :=
Block[{list = List @@ X},
Length[list]

$$\sum_{j=2} \langle \text{list}[[1]], \text{list}[[j]] \rangle \text{wick}[\text{Times} @@ \text{Drop}[\text{Drop}[\text{list}, \{j\}], 1]]]$$

```

■ Computing the Wick contractions

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[  $k_{i_}$   $\Leftrightarrow$   $k[i_]$  ]
```

```
(* vertex[n_,  $\alpha_$ ] :=  $\prod_{j=1}^n \phi[k_{\alpha[j]}]$ ; *)
```

Notation Palette

- Notation $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right]$
- Notation $\left[\begin{array}{c} \blacksquare \\ \Rightarrow \end{array} \right]$
- Notation $\left[\begin{array}{c} \blacksquare \\ \Leftarrow \end{array} \right]$
- Symbolize $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right]$
- InfixNotation $\left[\begin{array}{c} \blacksquare \\ \blacksquare, \blacksquare \end{array} \right]$
- AddInputAlias $\left[\begin{array}{c} \blacksquare \rightarrow \blacksquare \\ \blacksquare \end{array} \right]$
- Full Notation Palette

■ Function and Notation

In[35]:=

```
List @@ towick // TreeForm
```

In[36]:=

```
wick[X_Times] :=
Block[{list = List @@ X},
Length[list]
Sum[<list[[1]], list[[j]]> wick[Times @@ Drop[Drop[list, {j}], 1]],
j=2]
wick[φ[a_] φ[b_]] := <φ[a], φ[b]>
```

■ Computing the Wick contractions

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[ ki ⇔ k[i_] ]
```

Notation Palette

- Notation [$\leftrightarrow$]
- Notation [$\Rightarrow$]
- Notation [$\Leftarrow$]
- Symbolize []
- InfixNotation [,]
- AddInputAlias [$\rightarrow$]
- Full Notation Palette

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

Notation Palette

Notation $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right] \leftrightarrow \left[\begin{array}{c} \square \\ \square \end{array} \right]$

Notation $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right] \Rightarrow \left[\begin{array}{c} \square \\ \square \end{array} \right]$

Notation $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right] \Leftarrow \left[\begin{array}{c} \square \\ \square \end{array} \right]$

Symbolize $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right]$

InfixNotation $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right] , \left[\begin{array}{c} \square \\ \square \end{array} \right]$

AddInputAlias $\left[\begin{array}{c} \square \\ \square \end{array} \right] \rightarrow \left[\begin{array}{c} \square \\ \square \end{array} \right]$

Full Notation Palette

In[36]:=

```
wick[X_Times] :=
Block[{list = List @@ X},
  Length[list]
  Sum[<list[[1]], list[[j]]> wick[Times @@ Drop[Drop[list, {j}], 1]],
    {j, 2}
]
wick[phi[a_] phi[b_]] := <phi[a], phi[b]>
```

In[38]:=

```
wick[phi[k1] phi[k2]]
```

Out[38]=

```
<phi[k1], phi[k2]>
```

In[39]:=

```
wick[phi[k1] phi[k2] phi[k3] phi[k4]]
```

Out[39]=

```
<phi[k1], phi[k4]> <phi[k2], phi[k3]> + <phi[k1], phi[k3]> <phi[k2], phi[k4]> + <phi[k1], phi[k2]> <phi[k3], phi[k4]>
```

AngleBracket|

■ Computing the Wick contractions

200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

Mon 9:30 AM

Notation Palette

Notation $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right] \begin{array}{c} \leftarrow \\ \rightarrow \end{array} \square$

Notation $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right] \rightarrow \square$

Notation $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right] \leftarrow \square$

Symbolize $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right]$

InfixNotation $\left[\begin{array}{c} \blacksquare \\ \blacksquare \end{array} \right] , \square$

AddInputAlias $\square \rightarrow \square$

Full Notation Palette

In[36]:=

```
wick[X_Times] :=
Block[{list = List @@ X},
  Length[list]
  \sum_{j=2} \langle list[[1]], list[[j]] \rangle wick[Times @@ Drop[Drop[list, {j}], 1]]
wick[\phi[a_] \phi[b_]] := \langle \phi[a], \phi[b] \rangle
```

In[38]:=

```
wick[\phi[k_1] \phi[k_2]]
```

Out[38]=

$$\langle \phi[k_1], \phi[k_2] \rangle$$

In[39]:=

```
wick[\phi[k_1] \phi[k_2] \phi[k_3] \phi[k_4]]
```

Out[39]=

$$\langle \phi[k_1], \phi[k_4] \rangle \langle \phi[k_2], \phi[k_3] \rangle + \langle \phi[k_1], \phi[k_3] \rangle \langle \phi[k_2], \phi[k_4] \rangle + \langle \phi[k_1], \phi[k_2] \rangle \langle \phi[k_3], \phi[k_4] \rangle$$

In[42]:=

```
list
```

Out[42]=

```
list
```

200%

■ Function and Notation

In[36]:=

```
wick[X_Times] :=
Block[{list = List @@ X},
  Length[list]
  Sum[<list[[1]], list[[j]]> wick[Times @@ Drop[Drop[list, {j}], 1]],
  {j, 2}
]
wick[φ[a_] φ[b_]] := <φ[a], φ[b]>
```

Example:

In[39]:=

```
wick[φ[k1] φ[k2] φ[k3] φ[k4]]
```

Out[39]=

```
<φ[k1], φ[k4]] <φ[k2], φ[k3]] + <φ[k1], φ[k3]] <φ[k2], φ[k4]] + <φ[k1], φ[k2]] <φ[k3], φ[k4]]
```

■ Computing the Wick contractions

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[ ki ⇔ k[i_] ]
```

Notation Palette

- Notation []
- Notation []
- Notation []
- Symbolize []
- InfixNotation []
- AddInputAlias []
- Full Notation Palette

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

Notation Palette

Notation $\left[\begin{array}{c} \blacksquare \\ \blacktriangleright \end{array} \right]$

Notation $\left[\begin{array}{c} \blacksquare \\ \blacktriangleright \end{array} \right]$

Notation $\left[\begin{array}{c} \blacksquare \\ \blacktriangleright \end{array} \right]$

Symbolize $\left[\begin{array}{c} \blacksquare \\ \blacktriangleright \end{array} \right]$

InfixNotation $\left[\begin{array}{c} \blacksquare \\ \blacktriangleright \end{array} \right]$

AddInputAlias $\left[\begin{array}{c} \blacksquare \\ \blacktriangleright \end{array} \right]$

Full Notation Palette

$$\sum_{j=2}^{\text{Length}[\text{list}]} \langle \text{list}[[1]], \text{list}[[j]] \rangle \text{wick}[\text{Times} @@ \text{Drop}[\text{Drop}[\text{list}, \{j\}], 1]]]$$

wick $[\phi[a_]\phi[b_]] := \langle \phi[a], \phi[b] \rangle$

Example:

In[39]:= **wick** $[\phi[k_1]\phi[k_2]\phi[k_3]\phi[k_4]]$

Out[39]= $\langle \phi[k_1], \phi[k_4] \rangle \langle \phi[k_2], \phi[k_3] \rangle + \langle \phi[k_1], \phi[k_3] \rangle \langle \phi[k_2], \phi[k_4] \rangle + \langle \phi[k_1], \phi[k_2] \rangle \langle \phi[k_3], \phi[k_4] \rangle$

In[46]:= $\phi[k_1]\phi[k_2]\phi[k_3]\phi[k_4]$ // Head
List @@ $(\phi[k_1]\phi[k_2]\phi[k_3]\phi[k_4])$
Drop[Drop[%, {3}], 1]

Out[46]= Times

Out[47]= $\{\phi[k_1], \phi[k_2], \phi[k_3], \phi[k_4]\}$

Out[48]= $\{\phi[k_2], \phi[k_4]\}$

200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

Notation Palette

Notation | $\leftrightarrow$ |

Notation | $\Rightarrow$ |

Notation | $\Leftarrow$ |

Symbolize | |

InfixNotation | $\cdot$ |

AddInputAlias | $\rightarrow$ |

Full Notation Palette

$\sum_{j=2}^{\dots} \dots$

$\text{wick}[\phi[a_] \phi[b_]] := \langle \phi[a], \phi[b] \rangle$

Example:

In[39]:= $\text{wick}[\phi[k_1] \phi[k_2] \phi[k_3] \phi[k_4]]$

Out[39]= $\langle \phi[k_1], \phi[k_4] \rangle \langle \phi[k_2], \phi[k_3] \rangle + \langle \phi[k_1], \phi[k_3] \rangle \langle \phi[k_2], \phi[k_4] \rangle + \langle \phi[k_1], \phi[k_2] \rangle \langle \phi[k_3], \phi[k_4] \rangle$

In[51]:= $\text{wick}[\phi[k_1] \phi[k_2] \text{vertex}[4]]$

Out[51]= $\langle \phi[k_1], \phi[k_{\alpha 795[4]}] \rangle (\langle \phi[k_2], \phi[k_{\alpha 795[3]}] \rangle \langle \phi[k_{\alpha 795[1]}], \phi[k_{\alpha 795[2]}] \rangle + \langle \phi[k_2], \phi[k_{\alpha 795[2]}] \rangle \langle \phi[k_{\alpha 795[1]}], \phi[k_{\alpha 795[3]}] \rangle + \langle \phi[k_2], \phi[k_{\alpha 795[1]}] \rangle \langle \phi[k_{\alpha 795[2]}], \phi[k_{\alpha 795[3]}] \rangle) + \langle \phi[k_1], \phi[k_{\alpha 795[3]}] \rangle (\langle \phi[k_2], \phi[k_{\alpha 795[4]}] \rangle \langle \phi[k_{\alpha 795[1]}], \phi[k_{\alpha 795[2]}] \rangle + \langle \phi[k_2], \phi[k_{\alpha 795[2]}] \rangle \langle \phi[k_{\alpha 795[1]}], \phi[k_{\alpha 795[4]}] \rangle + \langle \phi[k_2], \phi[k_{\alpha 795[1]}] \rangle \langle \phi[k_{\alpha 795[2]}], \phi[k_{\alpha 795[4]}] \rangle) + \langle \phi[k_1], \phi[k_{\alpha 795[2]}] \rangle (\langle \phi[k_2], \phi[k_{\alpha 795[4]}] \rangle \langle \phi[k_{\alpha 795[1]}], \phi[k_{\alpha 795[3]}] \rangle + \langle \phi[k_2], \phi[k_{\alpha 795[3]}] \rangle \langle \phi[k_{\alpha 795[1]}], \phi[k_{\alpha 795[4]}] \rangle + \langle \phi[k_2], \phi[k_{\alpha 795[1]}] \rangle \langle \phi[k_{\alpha 795[3]}], \phi[k_{\alpha 795[4]}] \rangle) + \langle \phi[k_1], \phi[k_{\alpha 795[1]}] \rangle (\langle \phi[k_2], \phi[k_{\alpha 795[4]}] \rangle \langle \phi[k_{\alpha 795[2]}], \phi[k_{\alpha 795[3]}] \rangle + \langle \phi[k_2], \phi[k_{\alpha 795[3]}] \rangle \langle \phi[k_{\alpha 795[2]}], \phi[k_{\alpha 795[4]}] \rangle + \langle \phi[k_2], \phi[k_{\alpha 795[2]}] \rangle \langle \phi[k_{\alpha 795[3]}], \phi[k_{\alpha 795[4]}] \rangle) +$

200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

Notation $k_i \Leftrightarrow k[i]$

```
(* vertex[n_, α_] := ∏j=1n φ[kα[j]]; *)
```

```
vertex[n_] := Block[{letter = Unique[α]}, ∏j=1n φ[kletter[j]]]
```

In[30]:=

```
towick = φ[k1] φ[k2] vertex[4] vertex[4];
```

```
EvenQ@Count[towick, φ[_]]
```

Out[31]=

True

In[52]:=

```
wickcontracted = Expand@wick@towick
```

Out[52]=

A very large output was generated. Here is a sample of it:

$$\langle \phi[k_1], \phi[k_{\alpha 639[4]}] \rangle \langle \phi[k_2], \phi[k_{\alpha 639[3]}] \rangle \langle \phi[k_{\alpha 638[1]}], \phi[k_{\alpha 639[2]}] \rangle$$

$$\langle \phi[k_{\alpha 638[2]}], \phi[k_{\alpha 639[1]}] \rangle \langle \phi[k_{\alpha 638[3]}], \phi[k_{\alpha 638[4]}] \rangle + \ll 943 \gg + \langle \phi[k_1], \phi[k_2] \rangle \ll 4 \gg$$

Show Less Show More Show Full Output Set Size Limit...

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Untitled-4

Out[31]=

True

In[52]:=

wickcontracted = Expand@wick@towick

Out[52]=

A very large output was generated. Here is a sample of it:

$$\langle \phi[k_1], \phi[k_{\alpha 639[4]}] \rangle \langle \phi[k_2], \phi[k_{\alpha 639[3]}] \rangle \langle \phi[k_{\alpha 638[1]}], \phi[k_{\alpha 639[2]}] \rangle$$

$$\langle \phi[k_{\alpha 638[2]}], \phi[k_{\alpha 639[1]}] \rangle \langle \phi[k_{\alpha 638[3]}], \phi[k_{\alpha 638[4]}] \rangle + \ll 943 \gg + \langle \phi[k_1], \phi[k_2] \rangle \ll 4 \gg$$

Show Less Show More Show Full Output Set Size Limit...

In[53]:=

Length[wickcontracted]

Out[53]=

945

■ Plotting t

200%

Notation Palette

Notation | $\leftrightarrow$ |

Notation | $\Rightarrow$ |

Notation | $\Leftarrow$ |

Symbolize | |

InfixNotation | $\cdot$ |

AddInputAlias | $\rightarrow$ |

Full Notation Palette

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

In[36]:=

```

wick[X_Times] :=
Block[{list = List @@ X},
  Length[list]
  Sum[<list[[1]], list[[j]]> wick[Times @@ Drop[Drop[list, {j}], 1]], {j, 2, Length[list]}]
wick[phi[a_] phi[b_]] := <phi[a], phi[b]>

```

Example:

In[39]:=

```

wick[phi[k1] phi[k2] phi[k3] phi[k4]]

```

Out[39]=

$$\langle \phi[k_1], \phi[k_4] \rangle \langle \phi[k_2], \phi[k_3] \rangle + \langle \phi[k_1], \phi[k_3] \rangle \langle \phi[k_2], \phi[k_4] \rangle + \langle \phi[k_1], \phi[k_2] \rangle \langle \phi[k_3], \phi[k_4] \rangle$$

In[54]:=

```

wickcontracted[1]

```

Out[54]=

$$\langle \phi[k_1], \phi[k_{\alpha 639[4]}] \rangle \langle \phi[k_2], \phi[k_{\alpha 639[3]}] \rangle \langle \phi[k_{\alpha 638[1]}], \phi[k_{\alpha 639[2]}] \rangle \\ \langle \phi[k_{\alpha 638[2]}], \phi[k_{\alpha 639[1]}] \rangle \langle \phi[k_{\alpha 638[3]}], \phi[k_{\alpha 638[4]}] \rangle$$

■ Computing the Wick contractions

200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Untitled-4

Out[39]=

$$\langle \phi[k_1], \phi[k_4] \rangle \langle \phi[k_2], \phi[k_3] \rangle + \langle \phi[k_1], \phi[k_3] \rangle \langle \phi[k_2], \phi[k_4] \rangle + \langle \phi[k_1], \phi[k_2] \rangle \langle \phi[k_3], \phi[k_4] \rangle$$

In[54]:=

```
wickcontracted[[1]]
```

Out[54]=

$$\langle \phi[k_1], \phi[k_{\alpha 639[4]}] \rangle \langle \phi[k_2], \phi[k_{\alpha 639[3]}] \rangle \langle \phi[k_{\alpha 638[1]}], \phi[k_{\alpha 639[2]}] \rangle$$

$$\langle \phi[k_{\alpha 638[2]}], \phi[k_{\alpha 639[1]}] \rangle \langle \phi[k_{\alpha 638[3]}], \phi[k_{\alpha 638[4]}] \rangle$$

■ Computing the Wick contractions

In[7]:=

```
<< Notation`
```

In[9]:=

```
Notation[ k_i_ <=> k[i_] ]
```

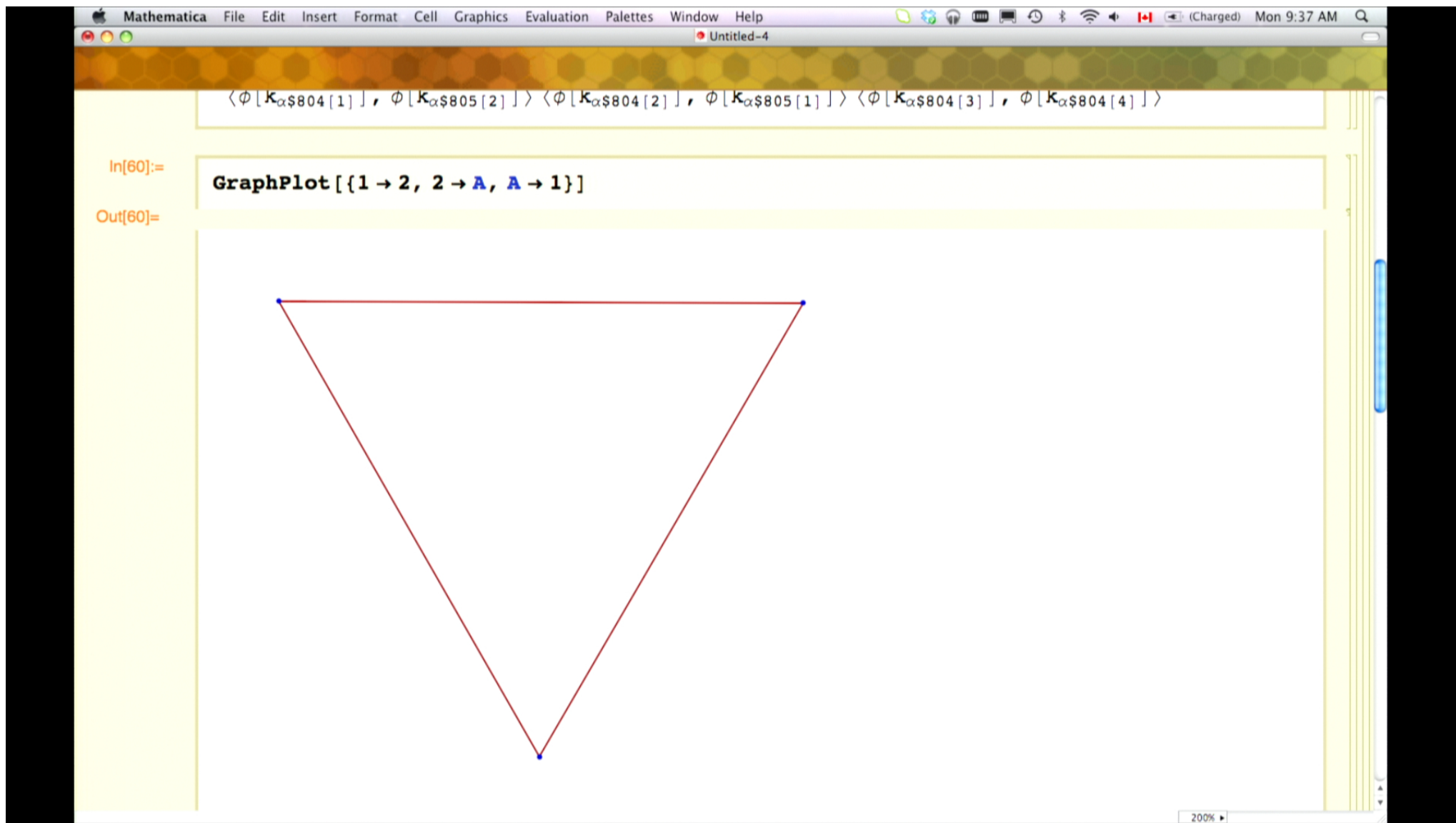
```
(* vertex[n_, α_] := ∏_{j=1}^n φ[k_{α[j]}]; *)
```

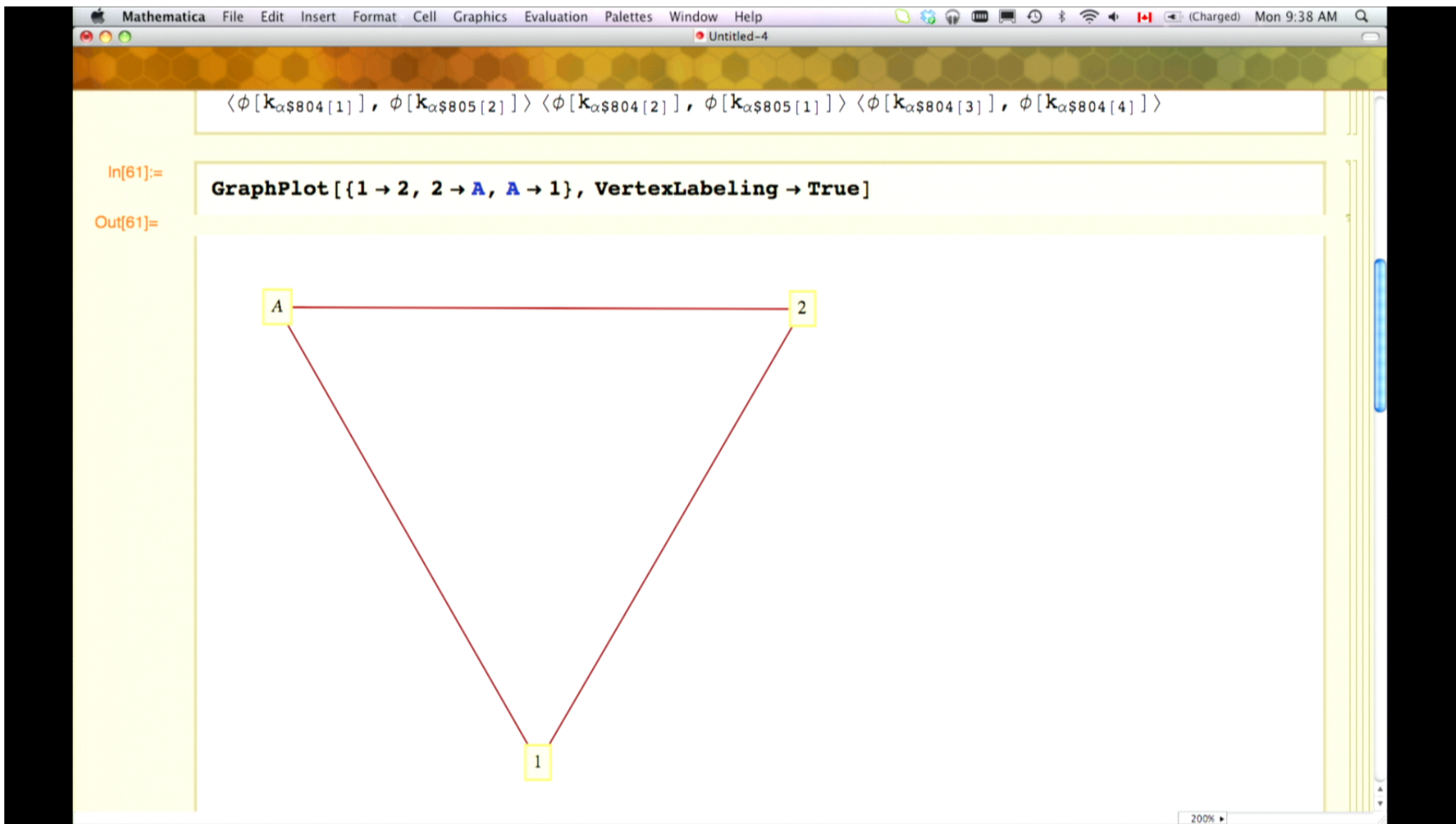
```
vertex[n_] := Block[{letter = Unique[α]}, ∏_{j=1}^n φ[k_{letter[j]}]]
```

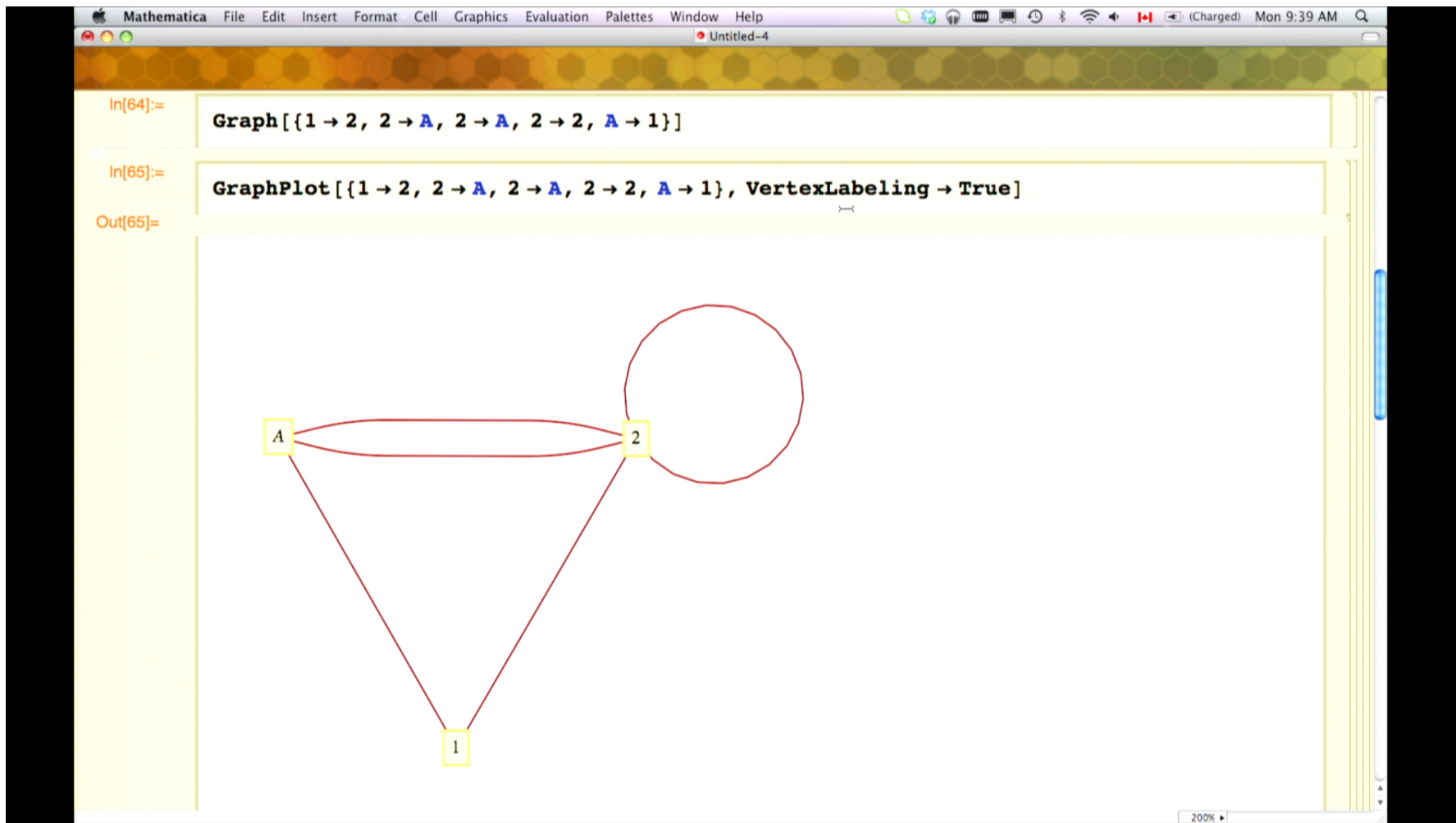
In[55]:=

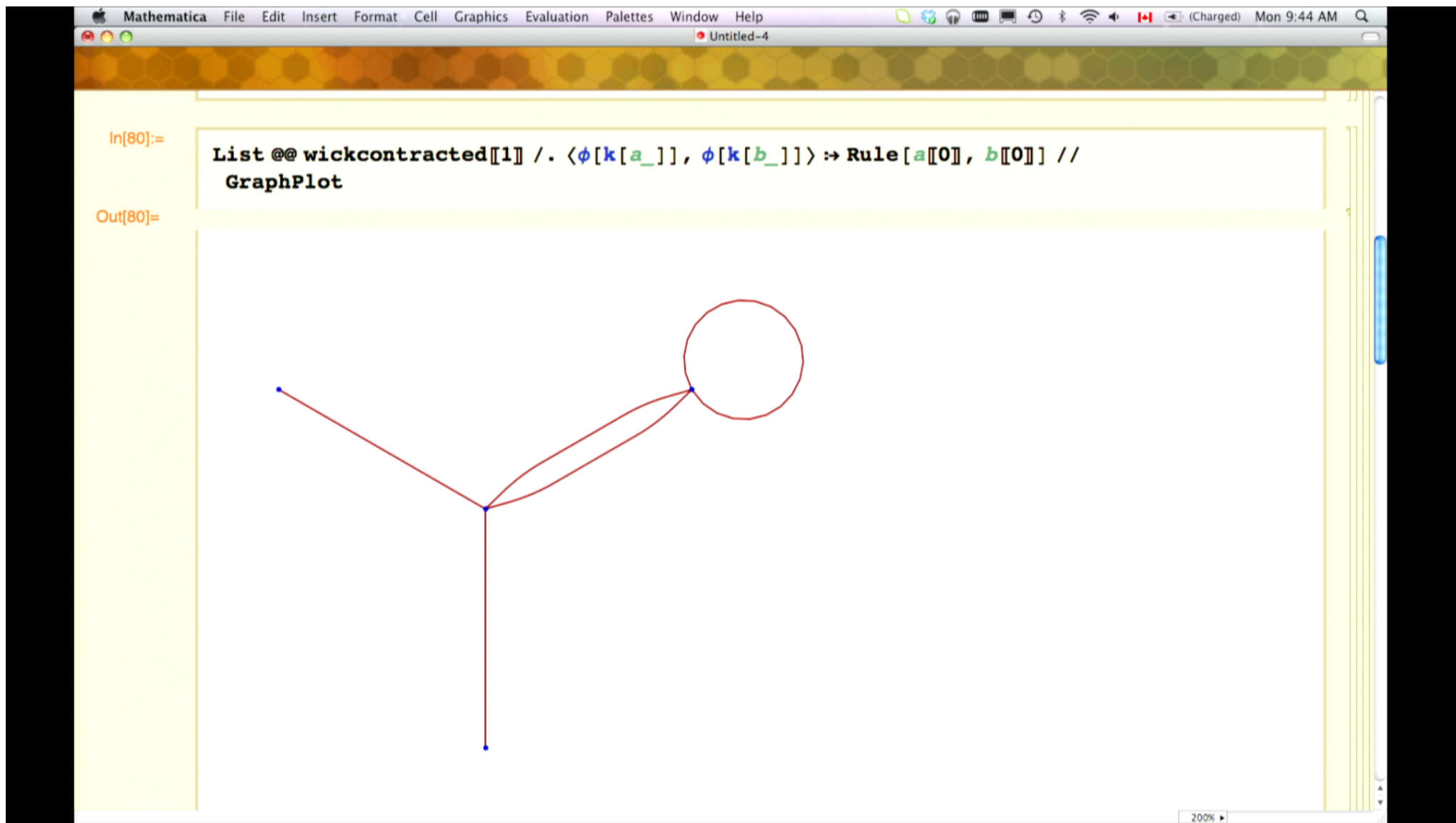
```
towick = φ[k_{1[1]}] φ[k_{2[1]}] vertex[4] vertex[4];
```

200%









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Untitled-4

$\langle \phi[k_1], \phi[k_4] \rangle \langle \phi[k_2], \phi[k_3] \rangle + \langle \phi[k_1], \phi[k_3] \rangle \langle \phi[k_2], \phi[k_4] \rangle + \langle \phi[k_1], \phi[k_2] \rangle \langle \phi[k_3], \phi[k_4] \rangle$

In[78]:= `List @@ wickcontracted[[1]] /. <math>\langle \phi[k[a_]], \phi[k[b_]] \rangle \Rightarrow \text{Rule}[a, b]</math>`

Out[78]= $\{1[] \rightarrow \alpha\$805[4], 2[] \rightarrow \alpha\$805[3], \alpha\$804[1] \rightarrow \alpha\$805[2], \alpha\$804[2] \rightarrow \alpha\$805[1], \alpha\$804[3] \rightarrow \alpha\$804[4]\}$

In[80]:= `List @@ wickcontracted[[1]] /. <math>\langle \phi[k[a_]], \phi[k[b_]] \rangle \Rightarrow \text{Rule}[a[[0]], b[[0]]]</math> // GraphPlot`

Out[80]=

200%

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Untitled-4

Out[39]=

$$\langle \phi[k_1], \phi[k_4] \rangle \langle \phi[k_2], \phi[k_3] \rangle + \langle \phi[k_1], \phi[k_3] \rangle \langle \phi[k_2], \phi[k_4] \rangle + \langle \phi[k_1], \phi[k_2] \rangle \langle \phi[k_3], \phi[k_4] \rangle$$

In[88]:=

```
List @@ wickcontracted[300] /. <math>\phi[k[a\_]], \phi[k[b\_]]> \Rightarrow \text{Rule}[a[[0]], b[[0]]] //
```

GraphPlot

Out[88]=



In[65]:=

```
GraphPlot[{1 -> 2, 2 -> A, 2 -> A, 2 -> 2, A -> 1}, VertexLabeling -> True]
```

Out[65]=



200%

$$(\lambda \phi^2 + \frac{\lambda}{4!} \phi^4)$$

$$-\frac{1}{2}$$



$$O(\lambda^2)$$

Text[Framed[b---],c---]

→ "" /; {b}[[1]] not
a number.

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

Out[95]=

Integer

```
(List @@ wickcontracted[1] /. <math>\phi[k[a_]], \phi[k[b_]]> \rightarrow \text{Rule}[a[[0]], b[[0]] //
```

```
GraphPlot[#, VertexLabeling \rightarrow \text{True}, ImageSize \rightarrow 200] \&) /.
```

```
Text[Framed[a___], b___] :>|
```

In[103]:=

```
(List @@ wickcontracted[1] /. <math>\phi[k[a_]], \phi[k[b_]]> \rightarrow \text{Rule}[a[[0]], b[[0]] //
```

```
GraphPlot[#, VertexLabeling \rightarrow \text{True}, ImageSize \rightarrow 200] \&) /. uglyboxes \rightarrow ""
```

Out[103]=

200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

Untitled-4

Out[95]=

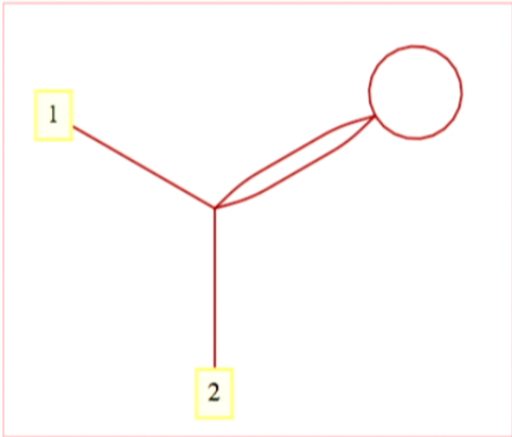
Integer

In[106]:=

```
(List @@ wickcontracted[1] /. <math display="block">\phi[k[a]], \phi[k[b]]> \Rightarrow \text{Rule}[a[[0]], b[[0]] //
```

GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] &) /.
 Text[Framed[a_], b_] -> "" /; ! NumericQ[{a}][1]

Out[106]=



In[103]:=

```
(List @@ wickcontracted[1] /. <math display="block">\phi[k[a]], \phi[k[b]]> \Rightarrow \text{Rule}[a[[0]], b[[0]] //
```

GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] &) /. uglyboxes -> ""

200%

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Untitled-4

Out[95]=

Integer

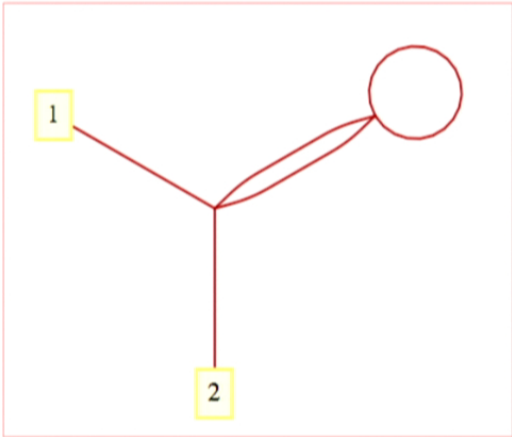
In[118]:=

```
List @@ wickcontracted[1] /. <math>\phi[k[a\_]], \phi[k[b\_]]> \rightarrow \text{Rule}[a[[0]], b[[0]]] //
```

```
GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] /.
```

```
Text[Framed[c___], b___] /; ! NumericQ[{c}][1] -> "" &
```

Out[118]=



In[103]:=

```
(List @@ wickcontracted[1] /. <math>\phi[k[a\_]], \phi[k[b\_]]> \rightarrow \text{Rule}[a[[0]], b[[0]]] //
```

```
GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] &) /. uglyboxes -> ""
```

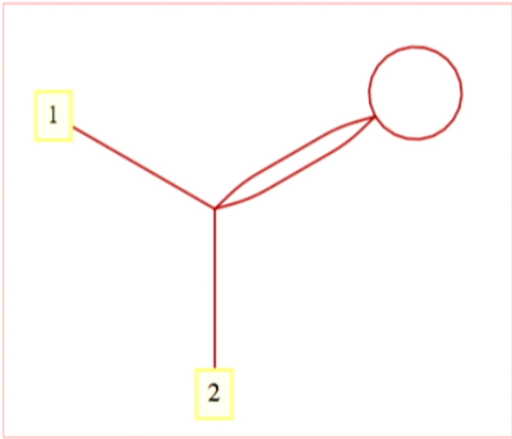
200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Untitled-4

In[126]:=

```
tograph@wickcontracted[[1]]
```

Out[126]=



In[125]:=

```
tograph[term_] := List @@ term /. <math>\phi[k[a\_]]</math>, <math>\phi[k[b\_]]</math>> => Rule[a[[0]], b[[0]]] //
  GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] /.
  Text[Framed[c___], b___] /; ! NumericQ[{c}[[1]]] => "" &
```

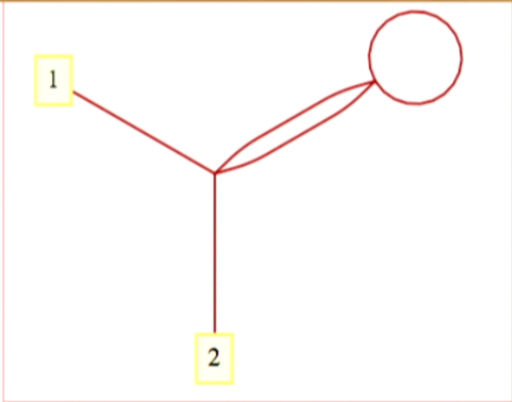
In[103]:=

```
(List @@ wickcontracted[[1]] /. <math>\phi[k[a\_]]</math>, <math>\phi[k[b\_]]</math>> => Rule[a[[0]], b[[0]]] //
  GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] &) /. uclvboxes -> ""
```

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Untitled-4



In[129]:=

```
tograph[term_] := |
  (List @@ term /. <math>\phi[k[a\_]]</math>, <math>\phi[k[b\_]]</math>> => Rule[a[[0]], b[[0]]] //
  GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] &) /.
  Text[Framed[c___], b___] /; ! NumericQ[{c}[[1]]] => ""
```

In[103]:=

```
(List @@ wickcontracted[1] /. <math>\phi[k[a\_]]</math>, <math>\phi[k[b\_]]</math>> => Rule[a[[0]], b[[0]]] //
  GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] &) /. uglyboxes -> ""
```

Out[103]=



200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

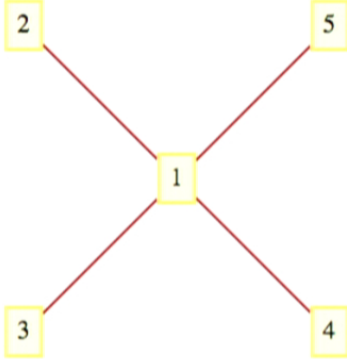
Untitled-4

2

In[136]:=

`tograph@wickcontracted[1]`

Out[136]=



```

ClearAll[tograph];
tograph[term_Times] :=
  tograph[term] = (List @@ term) /. <math>\phi[k[a\_]], \phi[k[b\_]]> \Rightarrow \{a[0] \rightarrow b[0]\}& //
    GraphPlot[#, VertexLabeling \rightarrow True, ImageSize \rightarrow 150] /.
      Text[Framed[b_, c_]; ! NumericQ[{b}[1]] \Rightarrow "" &

```

200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Untitled-4

In[147]:=

```
ClearAll[tograph];
tograph[term_Times] :=
tograph[term] = (List @@ term) /. <math>\phi[k[a\_]], \phi[k[b\_]]> \Rightarrow \{a[[0]] \rightarrow b[[0]]\} //
  GraphPlot[# // Flatten, VertexLabeling \rightarrow True, ImageSize \rightarrow 150] /.
  Text[Framed[b___], c___] /; ! NumericQ[{b}[[1]]] \Rightarrow "" &
```

In[144]:=

```
ClearAll[tograph]
tograph[term_] :=
tograph[term] =
  (List @@ term /. <math>\phi[k[a\_]], \phi[k[b\_]]> \Rightarrow \{a[[0]] \rightarrow b[[0]]\} //
    GraphPlot[# // Flatten, VertexLabeling \rightarrow True, ImageSize \rightarrow 200] &) /.
    Text[Framed[c___], b___] /; ! NumericQ[{c}[[1]]] \Rightarrow "";
```

In[103]:=

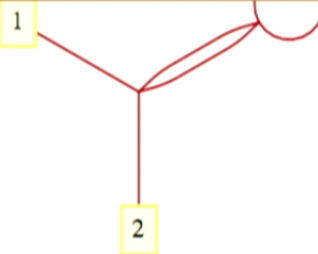
```
(List @@ wickcontracted[[1]] /. <math>\phi[k[a\_]], \phi[k[b\_]]> \Rightarrow \text{Rule}[a[[0]], b[[0]]] //
  GraphPlot[#, VertexLabeling \rightarrow True, ImageSize \rightarrow 200] &) /. uglyboxes \rightarrow ""
```

Out[103]=



200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Untitled-4



In[153]:=

```

ClearAll[tograph];
tograph[term_Times] :=
  tograph[term] = (List @@ term) /. <math>\phi[k[a\_]], \phi[k[b\_]]> \Rightarrow \{a[[0]] \rightarrow b[[0]]\}> //
    GraphPlot[# // Flatten, VertexLabeling -> True, ImageSize -> 150] /.
      Text[Framed[b___], c___] /; ! NumericQ[{b}[[1]]] => "" &

```

""

In[150]:=

```

ClearAll[tograph]
tograph[term_] :=
  tograph[term] =
    ((List @@ term) /. <math>\phi[k[a\_]], \phi[k[b\_]]> \Rightarrow \{a[[0]] \rightarrow b[[0]]\}> //
      GraphPlot[# // Flatten, VertexLabeling -> True, ImageSize -> 200] &) /.
        Text[Framed[c___], b___] /; ! NumericQ[{c}[[1]]] => "";

```

200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Untitled-4

```

GraphPlot[# // Flatten, VertexLabeling → True, ImageSize → 150] /.
Text[Framed[b___], c___] /; ! NumericQ[{b}[1]] := "" &

ClearAll[tograph]
tograph[term_] :=
tograph[term] =
(List @@ term) /. <math>\phi[k[a\_]], \phi[k[b\_]]> \Rightarrow \{a[0] \rightarrow b[0]\}> //
GraphPlot[# // Flatten, VertexLabeling → True, ImageSize → 200] &) /.
Text[Framed[c___], b___] /; ! NumericQ[{c}[1]] := "";

In[167]:=
"" // FullForm

Out[167]//FullForm=
""

In[168]:=
"" // FullForm

Out[168]//FullForm=
Text[""]

In[103]:=
(List @@ wickcontracted[1] /. <math>\phi[k[a\_]], \phi[k[b\_]]> \Rightarrow \text{Rule}[a[0], b[0]] //
GraphPlot[# // Flatten, VertexLabeling → True, ImageSize → 200] &) /; ! NumericQ[{a}[1]] := ""

```

200%

```

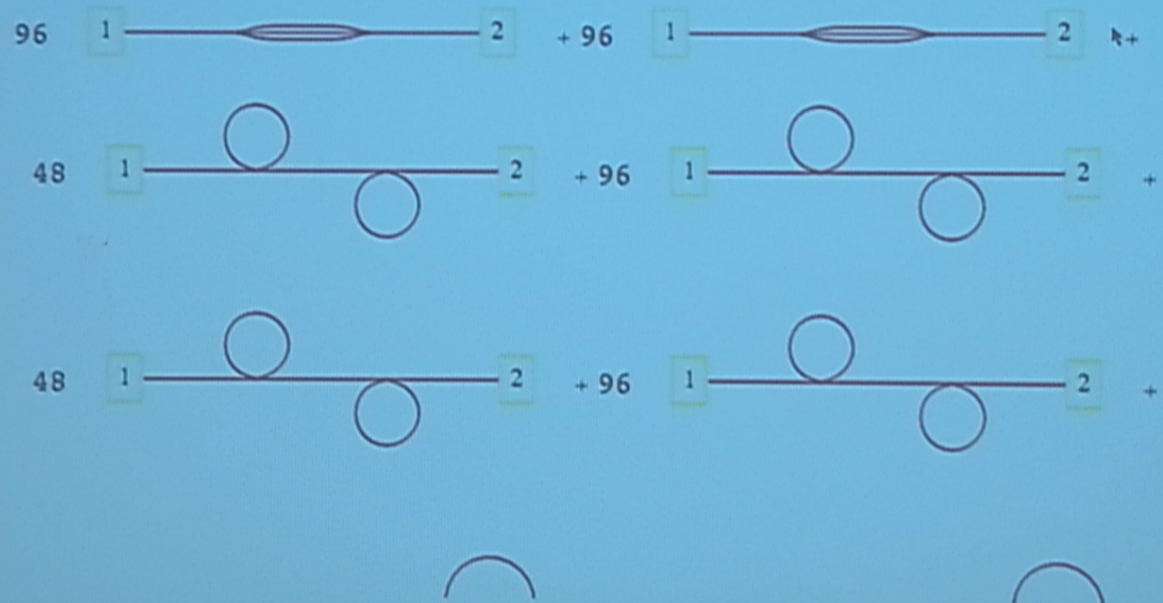
Circular[tograph]
tograph[term_] :=
tograph[term] =
(List @@ term /. {ϕ[k[a_]], ϕ[k[b_]]} => Rule[a[[0]], b[[0]]] //
  GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] &) /.
  Text[Framed[c___], b___] /; ! NumericQ[{c}[[1]]] => Text[""]

```

In[178]:=

tograph /@ wickcontracted

Out[178]=



Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
Untitled-4

`wick[ $\phi[k_1]$   $\phi[k_2]$   $\phi[k_3]$   $\phi[k_4]$ ]`

Out[39]=

$$\langle \phi[k_1], \phi[k_4] \rangle \langle \phi[k_2], \phi[k_3] \rangle + \langle \phi[k_1], \phi[k_3] \rangle \langle \phi[k_2], \phi[k_4] \rangle + \langle \phi[k_1], \phi[k_2] \rangle \langle \phi[k_3], \phi[k_4] \rangle$$

In[173]:=

```

ClearAll[tograph]
tograph[term_] :=
tograph[term] =
(List @@ term /. <math>\phi[k[a\_]]</math>, <math>\phi[k[b\_]]</math>)> => Rule[a[[0]], b[[0]]] //
  GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] &) /.
  Text[Framed[c___], b___] /; ! NumericQ[{c}[[1]]] => Text[""]

```

In[178]:=

`tograph /@ wickcontracted`

Out[178]=

96 + 96 +

48 + 96 +

200%

$$\langle \phi[k_1], \phi[k_4] \rangle \langle \phi[k_2], \phi[k_3] \rangle + \langle \phi[k_1], \phi[k_3] \rangle \langle \phi[k_2], \phi[k_4] \rangle + \langle \phi[k_1], \phi[k_2] \rangle \langle \phi[k_3], \phi[k_4] \rangle$$

In[173]:=

```
ClearAll[tograph]
tograph[term_] :=
tograph[term] =
(List @@ term /. <phi[k[a_]], phi[k[b_]]> => Rule[a[[0]], b[[0]]] //
  GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] &) /.
Text[Framed[c___], b___] /; ! NumericQ[{c}][[1]] => Text[""]
```

In[179]:=

96 + 96

Out[179]:=

192

In[180]:=

$$(96 + 96) \frac{1}{2!} \left(\frac{1}{4!} \right)^2$$

Out[180]:=

$$\frac{1}{6}$$

In[178]:=

Out[179]=

192

In[180]:=

$$(96 + 96) \frac{1}{2!} \left(\frac{1}{4!} \right)^2$$

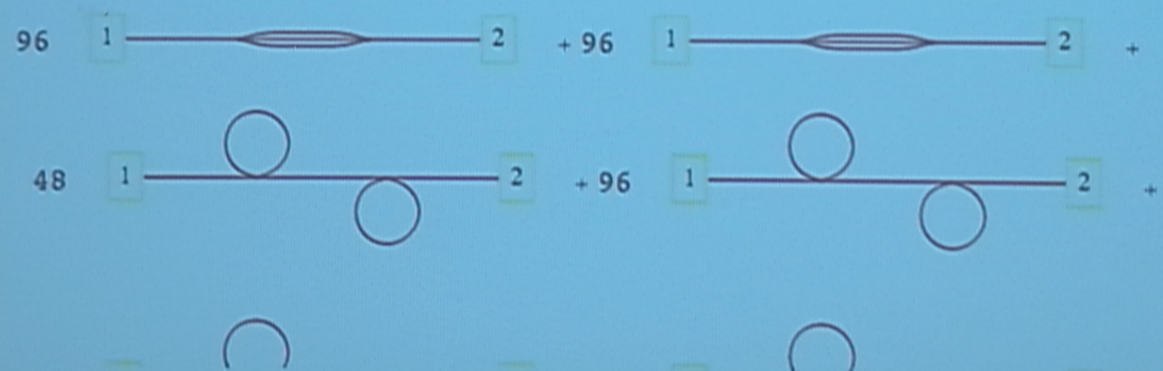
Out[180]=

$\frac{1}{6}$

In[178]:=

tograph /@ wickcontracted

Out[178]=



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FileBefore1010.nb

In[36]:=

```
wick[X_Times] :=
Block[{list = List @@ X},
  Length[list]
  Sum[⟨list[[1]], list[[j]]⟩ wick[Times @@ Drop[Drop[list, {j}], 1]], {j, 2}]]
wick[ϕ[a_] ϕ[b_]] := ⟨ϕ[a], ϕ[b]⟩
```

Example:

In[39]:=

```
wick[ϕ[k1] ϕ[k2] ϕ[k3] ϕ[k4]]
```

Out[39]=

$$\langle \phi[k_1], \phi[k_4] \rangle \langle \phi[k_2], \phi[k_3] \rangle + \langle \phi[k_1], \phi[k_3] \rangle \langle \phi[k_2], \phi[k_4] \rangle + \langle \phi[k_1], \phi[k_2] \rangle \langle \phi[k_3], \phi[k_4] \rangle$$

In[173]:=

```
ClearAll[tograph]
tograph[term_] :=
tograph[term] =
(List @@ term /. ⟨ϕ[k[a_]], ϕ[k[b_]]⟩ => Rule[a[[0]], b[[0]]] //
  GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] &) /.
Text[Framed[c___], b___] /; ! NumericQ[{c}[[1]]] => Text[""]
```

In[178]:=

200%

Mathematica File Edit Insert Format Cell Graphics Evaluation Palettes Window Help
FileBefore1010.nb

$j=2$

```
wick[ $\phi[a_]$   $\phi[b_]$ ] :=  $\langle \phi[a], \phi[b] \rangle$ 
```

Example:

In[39]:=

```
wick[ $\phi[k_1]$   $\phi[k_2]$   $\phi[k_3]$   $\phi[k_4]$ ]
```

Out[39]=

$$\langle \phi[k_1], \phi[k_4] \rangle \langle \phi[k_2], \phi[k_3] \rangle + \langle \phi[k_1], \phi[k_3] \rangle \langle \phi[k_2], \phi[k_4] \rangle + \langle \phi[k_1], \phi[k_2] \rangle \langle \phi[k_3], \phi[k_4] \rangle$$

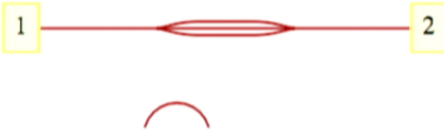
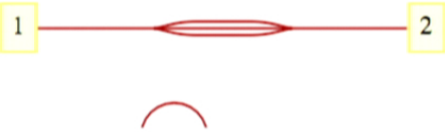
In[173]:=

```
ClearAll[tograph]
tograph[term_] :=
  tograph[term] =
    (List @@ term /.  $\langle \phi[k[a_]]$ ,  $\phi[k[b_]] \rangle \Rightarrow$  Rule[a[[0]], b[[0]]] //
      GraphPlot[#, VertexLabeling -> True, ImageSize -> 200] &) /.
      Text[Framed[c___], b___] /; ! NumericQ[{c}[[1]]] => Text[""]
```

In[178]:=

```
tograph /@ wickcontracted
```

Out[178]=

96  + 96  +

200%