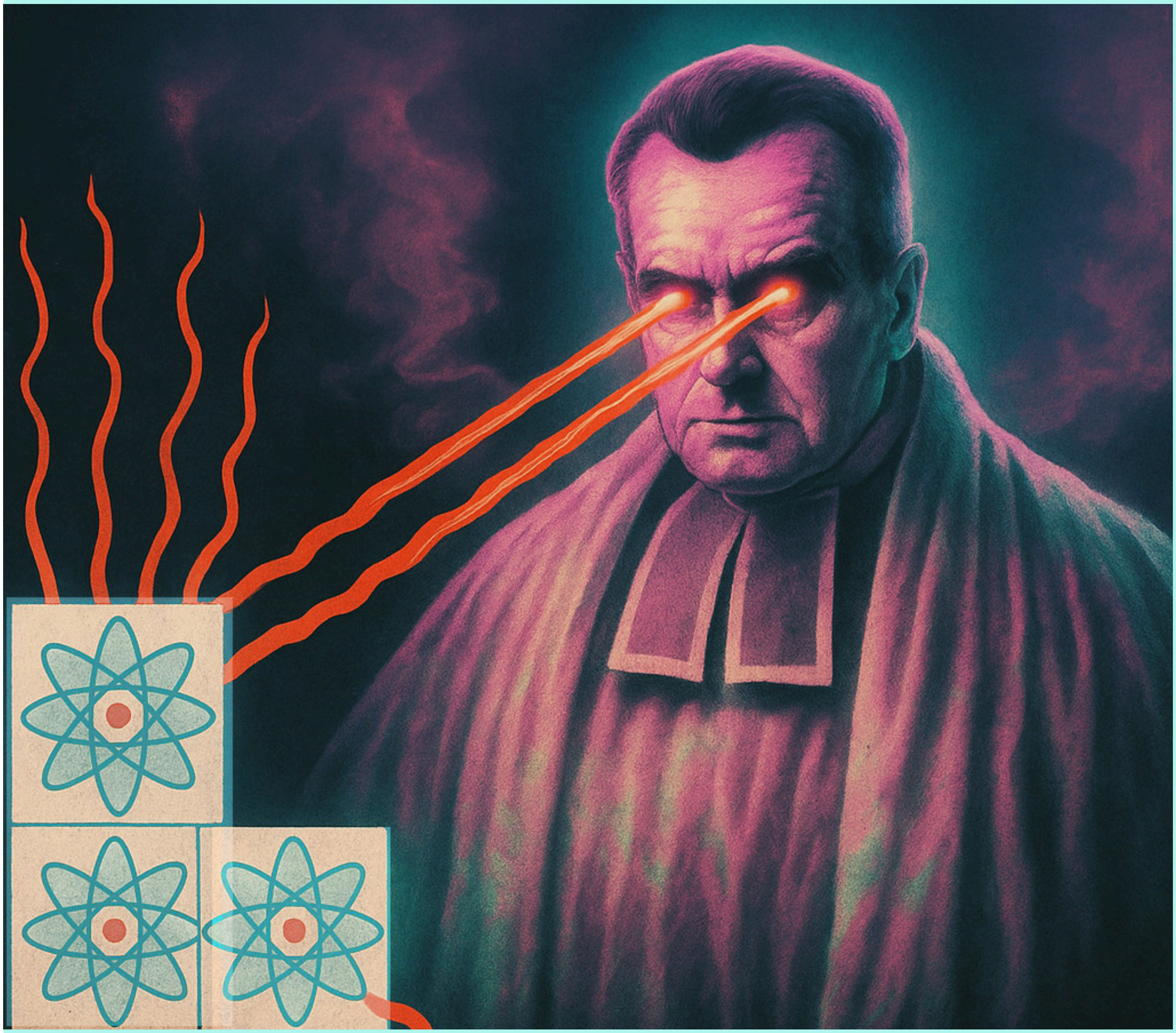
BAYESUVIUS QUANTICO

A VISUAL DICTIONARY OF QUANTUM BAYESIAN NETWORKS



ROBERT R. TUCCI

Bayesuvius Quantico,
a visual dictionary of Quantum Bayesian Networks

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This book is constantly being expanded and improved. To download the latest version, go to
`https://github.com/rrtucci/bayes-quantico`

Bayes Quantico
by Robert R. Tucci

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Appendix A

Spectral Decomposition and Eigenvalue Projection Operators: COMING SOON

$M \in \mathbb{C}^{d\times d}$

$$M|v\rangle = \lambda|v\rangle \tag{A.1}$$

If M is Hermitian ($H^\dagger = H$), its eigenvalues are real. ($\lambda = \langle\lambda|M\lambda\rangle \in \mathbb{R}$)

$$cp(\lambda) \stackrel{\text{def}}{=} \det(M - \lambda) = 0 \tag{A.2}$$

If M is a Hermitain matrix, then there exists a unitary matric ($CC^\dagger = C^\dagger C = 1$) such that

$$CMC^\dagger = \begin{bmatrix} D_{\lambda_1} & 0 & 0 & 0 \\ 0 & D_{\lambda_2} & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & D_{\lambda_r} \end{bmatrix} \tag{A.3}$$

where

$$D_{\lambda_i} = \mathrm{diag}\underbrace{(\lambda_i, \lambda_i, \ldots, \lambda_i)}_{d_i \text{ times}} \tag{A.4}$$

$$d = \sum_{i=1}^{r} d_i \tag{A.5}$$

$$CMC^\dagger = \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} \tag{A.6}$$

$$CP_1C^\dagger = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} = \frac{CMC^\dagger - \lambda_2}{\lambda_1 - \lambda_2} \tag{A.7}$$

$$CP_2C^\dagger = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} = \frac{CMC^\dagger - \lambda_1}{\lambda_2 - \lambda_1} \tag{A.8}$$

If $I^{d_i \times d_i}$ is the d_i dimensional unit matrix,

$$P_i = C^\dagger diag(0, \ldots, 0, I^{d_i \times d_i}, 0, \ldots, 0)C \tag{A.9}$$

$$= \prod_{j \neq i} \frac{M - \lambda_j}{\lambda_i - \lambda_j} \tag{A.10}$$

Note that P_i are Hermitian ($P_i^\dagger = P_i$) because M is Hermitian and its eigenvalues are real.)

Note that P_i and M commute

$$[P_i, M] = P_i M - M P_i = 0 \tag{A.11}$$

orthogonal

$$P_i P_j = \delta(i,j) P_j \tag{A.12}$$

complete

$$\sum_i P_i = 1 \tag{A.13}$$

$$M = \sum_{i=1}^{r} P_i M P_i \tag{A.14}$$

$$d_i = \mathrm{tr} P_i \tag{A.15}$$

$$CMP_1C^\dagger = \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \tag{A.16}$$

$$= \lambda_1 \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \tag{A.17}$$

$$MP_i = \lambda_i P_i \text{ (no } i \text{ sum)} \tag{A.18}$$

$$f(M)P_i = f(\lambda_i) P_i \text{ (no } i \text{ sum)} \tag{A.19}$$

$M^{(1)}, M^{(2)}$

$$[M^{(1)}, M^{(2)}] = 0 \tag{A.20}$$

Use $M^{(1)}$ to decompose V into $\bigoplus_i V_i$. Use $M^{(2)}$ to decompose V_i into $\bigoplus_j V_{i,j}$. If $M^{(1)}$ and $M^{(2)}$ don't commute, let $P_i^{(1)}$ be the eigenvalue projection operators of $M^{(1)}$. The replace $M^{(2)}$ by $P_i^{(1)} M^{(2)} P_i^{(1)}$

$$[M^{(1)}, P_i^{(1)} M^{(2)} P_i^{(1)}] = 0 \tag{A.21}$$

Appendix B

Birdtracks: COMING SOON

Cvitanovic Birdtracks book [1]
    Elliott-Dawber book [2]
    My paper "Quantum Bayesian Nets" [3]

B.1 Classical Bayesian Networks and their Instantiations

TPM (Transition Probability Matrix) $P(y|x) \in [0,1]$ where $x \in val(\underline{x})$ and $y \in val(\underline{y})$

$$\sum_{y \in val(\underline{y})} P(y|x) = 1 \tag{B.1}$$

$$\mathcal{C} = \begin{tikzcd} & \underline{b} \arrow[dl] & \\ \underline{c} & & \underline{a} \arrow[ul] \arrow[ll] \end{tikzcd} \tag{B.2}$$

$$\mathcal{C}(a,b,c) = P(c|b,a)P(b|a)P(a) = \begin{tikzcd} & b \arrow[dl] & \\ c & & a \arrow[ul] \arrow[ll] \end{tikzcd} \quad P(a) \tag{B.3}$$

$a^2 = (a_1, a_2)$

$$\mathcal{C}' = \begin{tikzcd} & \underline{b} \arrow[dl] & \\ \underline{c} & & \underline{a}^2 \arrow[ul, "\underline{a}_1"] \arrow[ll, "\underline{a}_2"] \end{tikzcd} \tag{B.4}$$

$$\mathcal{C}'(a^2,b,c) = P(c|b,a_2)P(a_2|a^2)P(b|a_1)P(a_1|a^2)P(a^2) = \begin{tikzcd} & b \arrow[dl] & \\ c & & a^2 \arrow[ul, "a_1"] \arrow[ll, "a_2"] \end{tikzcd} \quad P(a^2) \tag{B.5}$$

Marginalizer nodes $\underline{a}_1$ and $\underline{a}_2$ have the TPMs

$$P(a_i'|\underline{a}^2 = (a_1, a_2)) = \delta(a_i', a_i) \tag{B.6}$$

for $i = 1, 2$

B.2 Quantum Bayesian Networks and their Instantiations

TPM (Transition Probability Matrix) $A(y|x) \in \mathbb{C}$ where $x \in val(\underline{x})$ and $y \in val(\underline{y})$

$$\sum_{y \in val(\underline{y})} |A(y|x)|^2 = 1 \tag{B.7}$$

$$\mathcal{Q} = \begin{tikzcd} & \underline{b} \arrow[dl] & \\ \underline{c} & & \underline{a} \arrow[ul] \arrow[ll] \end{tikzcd} \tag{B.8}$$

$$\mathcal{Q}(a, b, c) = A(c|b, a)A(b|a)A(a) = \begin{tikzcd} & b \arrow[dl] & \\ c & & a \arrow[ul] \arrow[ll] \end{tikzcd} \quad A(a) \tag{B.9}$$

$a^2 = (a_1, a_2)$

$$\mathcal{Q}' = \begin{tikzcd} & \underline{b} \arrow[dl] & \\ \underline{c} & & \underline{a}^2 \arrow[ul, "\underline{a}_1"] \arrow[ll, "\underline{a}_2"] \end{tikzcd} \tag{B.10}$$

$$\mathcal{Q}'(a^2, b, c) = A(c|b, a_2)A(a_2|a^2)A(b|a_1)A(a_1|a^2)A(a^2) = \begin{tikzcd} & b \arrow[dl] & \\ c & & a^2 \arrow[ul, "a_1"] \arrow[ll, "a_2"] \end{tikzcd} \quad A(a^2) \tag{B.11}$$

Marginalizer nodes $\underline{a}_1$ and $\underline{a}_2$ have the TAMs

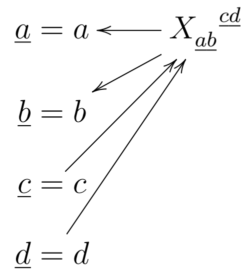
$$A(a_i'|\underline{a}^2 = (a_1, a_2)) = \delta(a_i', a_i) \tag{B.12}$$

for $i = 1, 2$

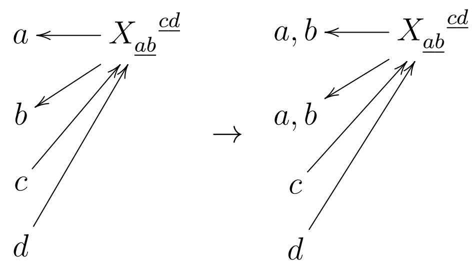
B.3 Birdtracks

$$\delta(b,a) = \mathbb{1}(a=b) = \delta_a^b = \; a \leftarrow\!\bullet\!- b \tag{B.13}$$

$$\langle a,b|X_{\underline{ab}}{}^{\underline{cd}}|c,d\rangle = X_{ab}{}^{cd} = \tag{B.14}$$

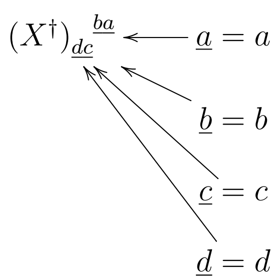


$$\tag{B.15}$$



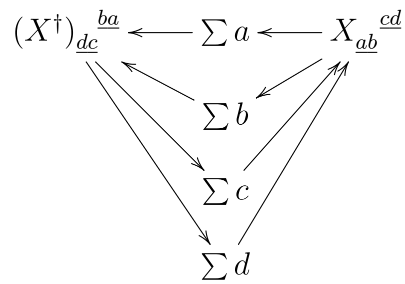
$X_{\underline{ab}}{}^{\underline{cd}} \in V^2 \otimes V_2$. Sometimes, we will omit denote this node simply by X. This if okay as long as we are not using, X to also denote a different version of $X_{\underline{ab}}{}^{\underline{cd}}$ with some of the indices raised or lowered or their order has been changed. [1]

$$(X^\dagger)_{dc}{}^{ba} = \tag{B.16}$$

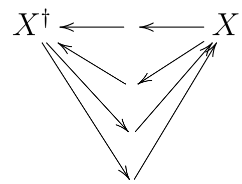


[1]For matrices, $(A^\dagger)_{i,j} = (A_{j,i})^*$ so taking a Hermitian conjugate involves both taking the complex conjugate of the matrix element and reversing the left-to-right (L2R) order of its indices. This generalizes to $(X^\dagger)_{dc}{}^{ba} = (X_{ab}{}^{cd})^*$. Besides raising and lowering indices, we reverse their L2R order.

$$(X^\dagger)_{dc}{}^{ba} X_{ab}{}^{cd} \quad = \tag{B.17}$$



$$= \tag{B.18}$$



Birdtracks originated as a graphical way to represent the tensors in General Relativity (Gravitation). In General Relativity, one deals with tensors such as $T_a{}^b{}_c$ which have some indices raised and some lowered. One can use the metric $g^{a,b}$ to raise all the lowered indices to get T^{abc}. If we represent this graphically as a node with incoming arrows a, b, c, we need to follow one of the following 2 conventions: either

1. label the arrows as $\underline{a}$, $\underline{b}, \underline{c}$, and define the node as $T^{\underline{abc}}$, or

2. instead of labelling the arrows explicitly $\underline{a}, \underline{b}, \underline{c}$, indicate in the node where is the first arrow $\underline{a}$, and draw the arrows $\underline{a}, \underline{b}, \underline{c}$ so that they enter the node in **counterclockwise** (CC) order. The **left-to-right** (L2R) order of the indices on T corresponds the CC order of the arrows.

If we don't do either 1 or 2, we won't be able to distinguish between the graphical representations of $T^{1,2,3}$ and $T^{2,1,3}$, for example. Cvitanovic's Birdtracks book Ref.[1] follows Convention 2, but most of the time, in this book, we will follow Convention 1 [2] The reason I chose to do so is for the sake of consistency: Convention 2 is closer to the quantum bnet conventions.

Another issue that arises in using birdtracks is this. When is it permissible to represent a tensor by T^{cd}_{ab}? If we define T^{cd}_{ab} by

$$T^{cd}_{ab} = T_{ab}{}^{cd} \tag{B.19}$$

then it's always permissible. Then one can define tensors like $T_a{}^{bcd}$ as

$$T_a{}^{bcd} = g^{bb'} T_{ab'}{}^{cd} = g^{bb'} T^{cd}_{ab'} \tag{B.20}$$

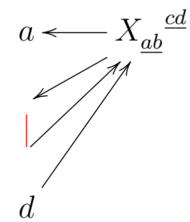
[2] If we follow Convention 1, we don't need to reverse the L2R order of the indices when taking a Hermitian conjugate. Thus, $(X^\dagger)^{\underline{ab}}{}_{\underline{cd}} = X_{\underline{ab}}{}^{\underline{cd}} = X^{\underline{dc}}{}_{\underline{ba}}$. As long as $\underline{a}, \underline{b}$ are lower indices and $\underline{c}, \underline{d}$ are upper indices of X, any L2R order of $\underline{a}, \underline{b}, \underline{c}, \underline{d}$ is equivalent under Convention 1.

Hence, one drawback of using the notation T_{ab}^{cd} is that if one is interested in using versions of T_{ab}^{cd} with some indices raised or lowered, one has to write down explicitly the metric tensors that do the lowering and raising. Instead of writing $T_a{}^{bcd}$, you'll have to write $g^{bb'}T_{ab'}^{cd}$. This is not very onerous when explaining a topic in which not much lowering and raising of indices is done. But in topics like General Relativity that do use a lot of raising and lowering of indices, it might not be too elegantly concise.

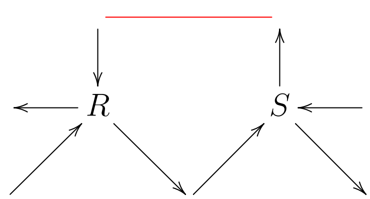
$a^m \in \mathbb{Z}_+^m$

$$R^{a_3^{m_3}, b_2^{n_2}}_{b_3^{n_3}, a_2^{m_2}} S^{a_2^{m_2}, b_1^{n_1}}_{b_2^{n_2}, a_1^{m_1}} = \begin{tikzcd} b_3^{n_3} & R \arrow[l] \arrow[dr] & \sum b_2^{n_2} \arrow[l] & S \arrow[l] \arrow[dr] & b_1^{n_1} \arrow[l] \\ a_3^{m_3} \arrow[ur] & & \sum a_2^{m_2} \arrow[ur] & & a_1^{m_1} \end{tikzcd} \tag{B.21}$$

$$\mathrm{tr}_{\underline{b}} X_{a\underline{b}}{}^{\underline{b}d} = \sum_b X_{ab}{}^{bd} = \tag{B.22}$$



(B.23)



Appendix C

Clebsch-Gordan Coefficients: COMING SOON

$$\begin{bmatrix} 0 \\ C_\lambda^{d_\lambda \times d} \\ 0 \end{bmatrix}^{d\times d} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & I^{d_\lambda \times d_\lambda} & 0 \\ 0 & 0 & 0 \end{bmatrix}^{d\times d} C^{d\times d} \tag{C.1}$$

Let $b^{nb} = (b_1, b_2, \ldots, b_{nb})$ where $b_i \in Z_{[0,db_i]}$ and $a \in Z_{[1,d_\lambda]}$. Hence,

$$d_\lambda = \prod_{i=1}^{nb} db_i \tag{C.2}$$

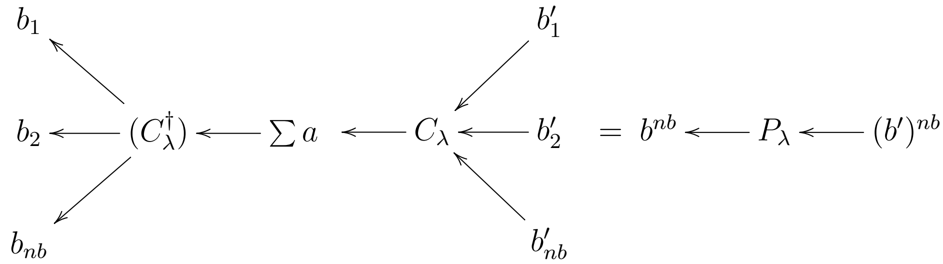
$$(C_\lambda)_a^{b^{nb}} = \begin{tikzcd} & & b_1 \arrow[dl] \\ a & C_\lambda \arrow[l] & b_2 \arrow[l] \\ & & b_{nb} \arrow[ul] \end{tikzcd} \tag{C.3}$$

$$\begin{bmatrix} 0 & (C^\dagger)_\lambda^{d\times d_\lambda} & 0 \end{bmatrix}^{d\times d} = (C^\dagger)^{d\times d} \begin{bmatrix} 0 & 0 & 0 \\ 0 & I^{d_\lambda \times d_\lambda} & 0 \\ 0 & 0 & 0 \end{bmatrix}^{d\times d} \tag{C.4}$$

$$(C_\lambda^\dagger)^a_{b^{nb}} = \begin{tikzcd} b_1 & & \\ b_2 & (C_\lambda^\dagger) \arrow[l] \arrow[ul] \arrow[dl] & a \arrow[l] \\ b_{nb} & & \end{tikzcd} \tag{C.5}$$

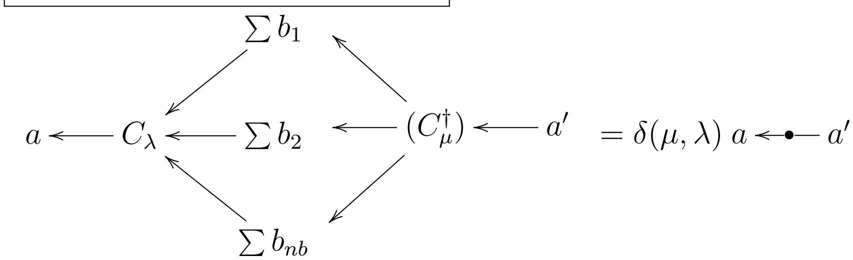
More generally, some of the b_i indices may lowered and their arrows changed to outgoing instead of ingoing. Each b_i represents a different rep (or irrep)

$$\boxed{(C^\dagger_\lambda)_a^{b^{nb}}(C_\lambda)^a_{(b')^{nb}} = (P_\lambda)^{b^{nb}}_{(b')^{nb}}}$$



(C.6)

$$\boxed{(C_\lambda)^{(a')^{na}}_{b^{nb}}(C^\dagger_\mu)^{b^{nb}}_a = \delta(\lambda,\mu)\delta^{(a')^{na}}_a}$$



(C.7)

Chapter 1

Casimir Operators: COMING SOON

Chapter 2

Determinants: COMING SOON

Chapter 3

General Relativity Nets: COMING SOON

Chapter 4

Group Integrals: COMING SOON

Chapter 5

Invariants: COMING SOON

Chapter 6

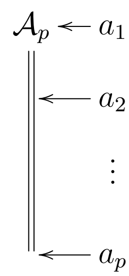
Levi-Civita Tensor

$$\epsilon^{123\ldots p} = \epsilon_{123\ldots p} = 1 \tag{6.1}$$

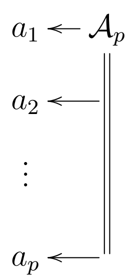
$$\epsilon_{rev(a^p)} = (-1)^{\binom{p}{2}} \epsilon_{a^p} \tag{6.2}$$

where $rev(a^p)$ is the reverse of a^p. $rev(a_1, a_2, \ldots, a_p) = (a_p, a_{p-1}, \ldots, a_1)$

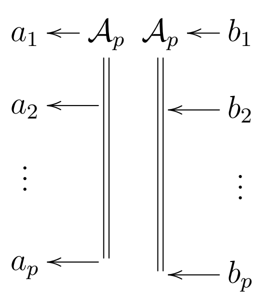
$$(C_{\mathcal{A}_p})_1^{a^p} = e^{i\phi} \frac{\epsilon^{a^p}}{\sqrt{p!}} = \tag{6.3}$$



$$(C^\dagger_{\mathcal{A}_p})^1_{a^p} = e^{-i\phi} \frac{\epsilon_{a^p}}{\sqrt{p!}} = \tag{6.4}$$



$$\boxed{\frac{1}{p!}\epsilon_{a^p}\epsilon^{b^p} = \mathcal{A}_{p\,a^p}^{\;\;b^p}} \tag{6.5}$$



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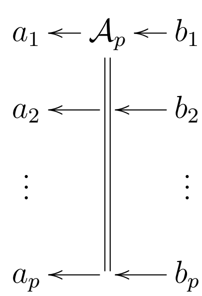
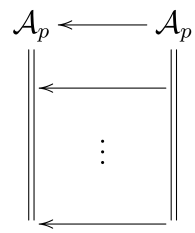


$$\boxed{e^{i2\phi}\frac{1}{p!}\epsilon^{a^n}\epsilon_{a^n} = \delta^1_1 = 1}$$



$$= 1 \qquad (6.6)$$

For Convention 1, we will use $\phi = 0$.
For Convention 2, we must choose

$$e^{i2\phi} = (-1)^{\binom{p}{2}} = e^{i\pi\frac{p(p-1)}{2}} \qquad (6.7)$$

so

$$\phi = \frac{\pi}{4}p(p-1) \qquad (6.8)$$

Chapter 7

Lie Algebra Definition: COMING SOON

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Lie Algebra Classification, Dynkin Diagrams: COMING SOON

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Chapter 16

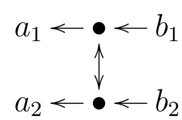
Symmetrization and Antisymmetrization: COMING SOON

$(1,2)$ transposition, swaps 1 and 2, $1 \to 2 \to 1$. $(3,2,1)$ means $3 \to 2 \to 1 \to 3$. A reordering of $(1,2,3,\ldots,p)$ is a permutation on p letters. A permutation can be expressed as a product of transpositions $(3,2,1) = (3,2)(2,1)$ is an even permutation because it can be expressed as a product of an even number of transpositions. An odd permutation can be expressed as a product of an odd number of permutations.

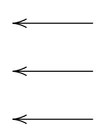
16.1 Symmetrization

$$\mathbb{1}^{b_2,b_1}_{a_1,a_2} = \delta^{b_1}_{a_1}\delta^{b_2}_{a_2} = \begin{array}{c} a_1 \leftarrow b_1 \\ \\ a_2 \leftarrow b_2 \end{array} \tag{16.1}$$

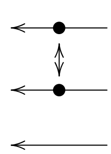
$$(\sigma_{(1,2)})^{b_2,b_1}_{a_1,a_2} = \delta^{b_2}_{a_1}\delta^{b_1}_{a_2} = \tag{16.2}$$



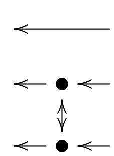
$$\mathbb{1} = \tag{16.3}$$



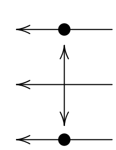
$$\sigma_{(1,2)} =$$

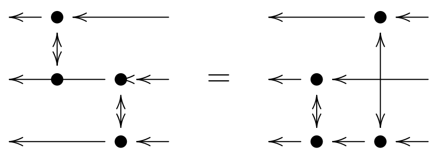


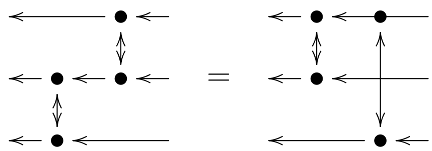
$$\sigma_{(2,3)} =$$

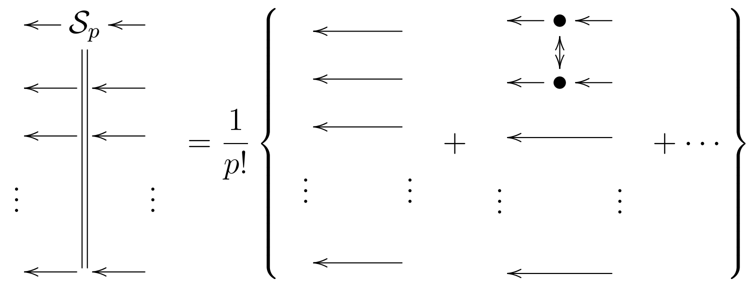


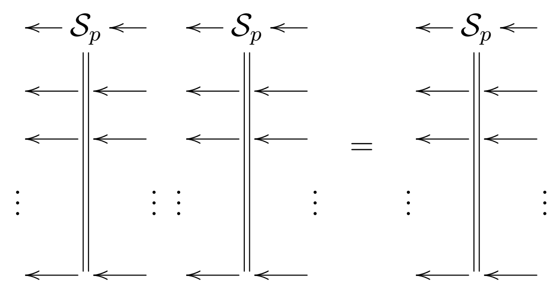
$$\sigma_{(1,3)} = \tag{16.4}$$

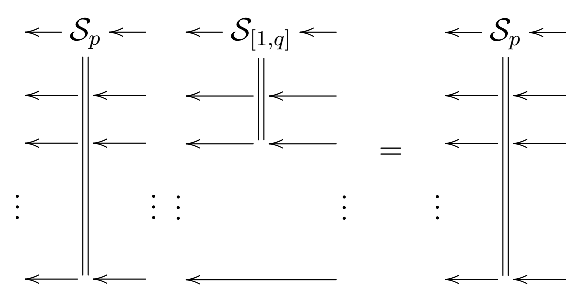


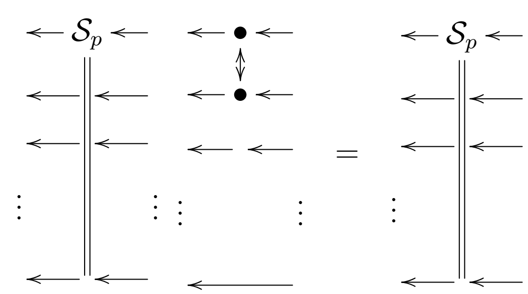
$\sigma_{(1,2,3)} =$  (16.5)

$\sigma_{(1,3,2)} =$  (16.6)

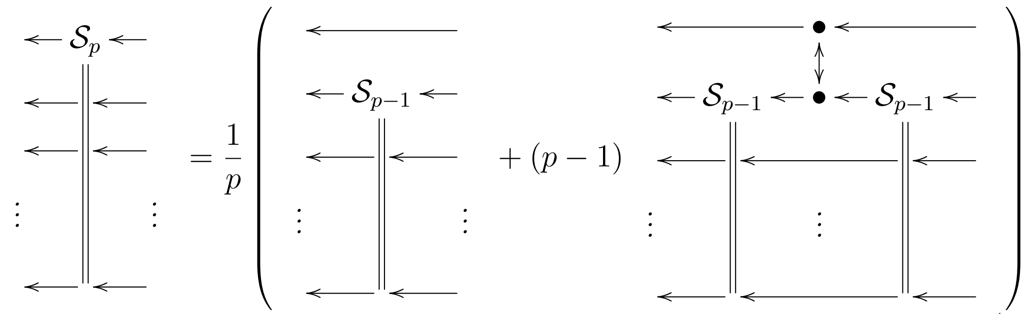
 (16.7)

$\boxed{\mathcal{S}_p^2 = \mathcal{S}_p}$  (16.8)

$\boxed{\mathcal{S}_p \mathcal{S}_{[1,q]} = \mathcal{S}_p}$  (16.9)

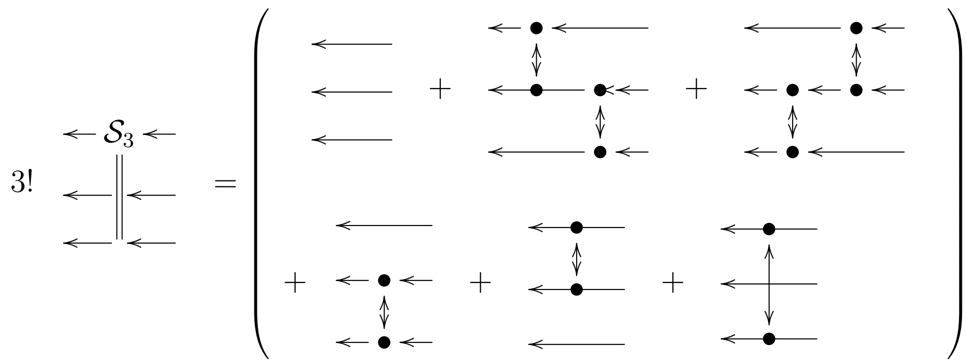
$\boxed{\mathcal{S}_p \sigma_{(1,2)} = \mathcal{S}_p}$  (16.10)

Claim 1

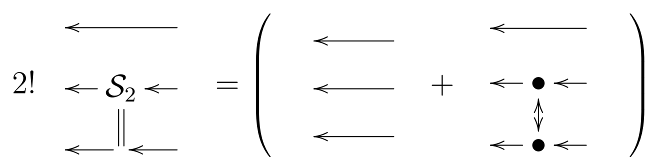


(16.11)

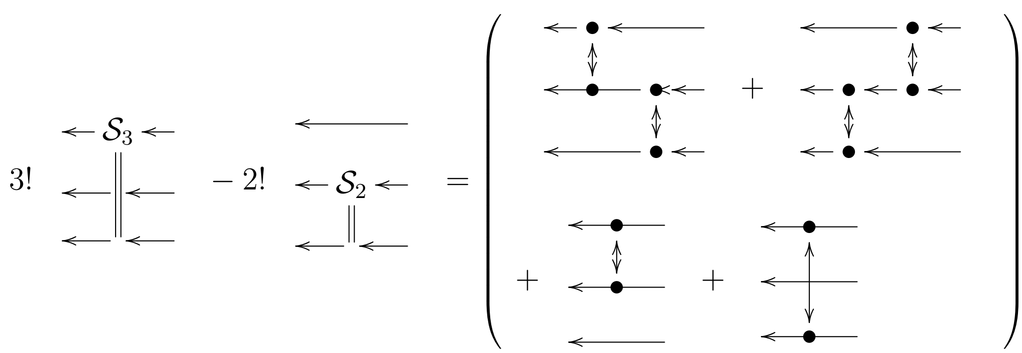
proof: We only prove it for $p = 3$.



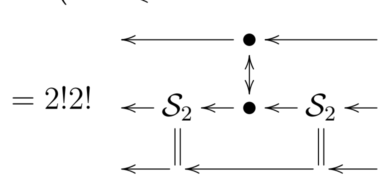
(16.12)



(16.13)

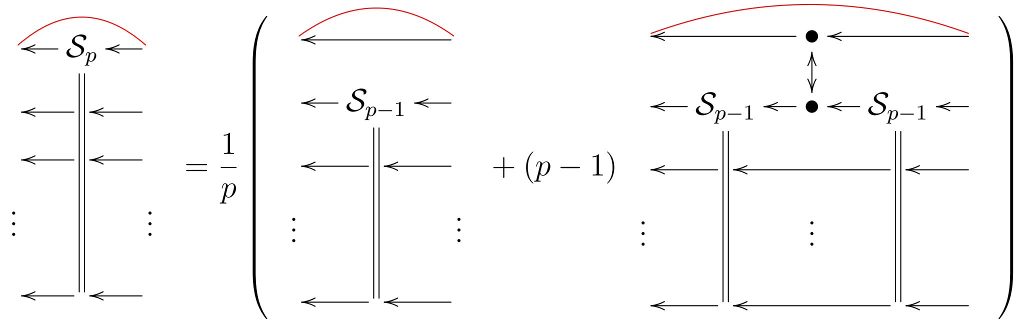


(16.14)

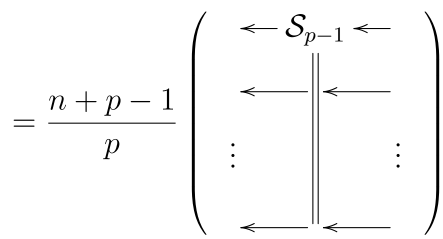


(16.15)

QED



(16.16)



(16.17)

$$\mathrm{tr}_{\underline{a}_1}\mathcal{S}_p = \frac{n+p-1}{p}\mathcal{S}_{p-1} \tag{16.18}$$

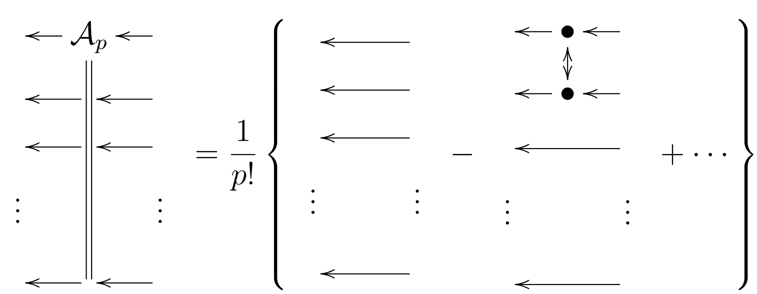
$$\mathrm{tr}_{\underline{a}_1,\underline{a}_2,\ldots,\underline{a}_k}\mathcal{S}_p = \frac{(n+p-1)(n+p-2)\ldots(n=p-k)}{p(p-1)\ldots(p-k+1)}\mathcal{S}_{p-k} \tag{16.19}$$

$$d_{\mathcal{S}_p} = \mathrm{tr}_{\underline{a}^p}\mathcal{S}_p = \frac{(n+p-1)!}{p!(n-1)!} = \binom{n+p-1}{p} \tag{16.20}$$

For $p = 2$,

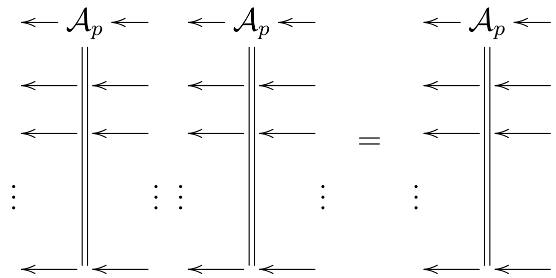
$$d_{\mathcal{S}_2} = \frac{(n+1)n}{2} \tag{16.21}$$

16.2 Antisymmetrization



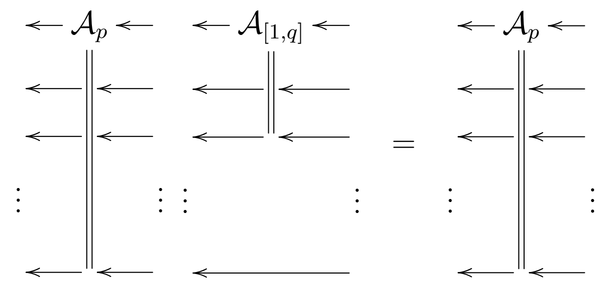
(16.22)

$$\boxed{\mathcal{A}_p^2 = \mathcal{A}_p}$$



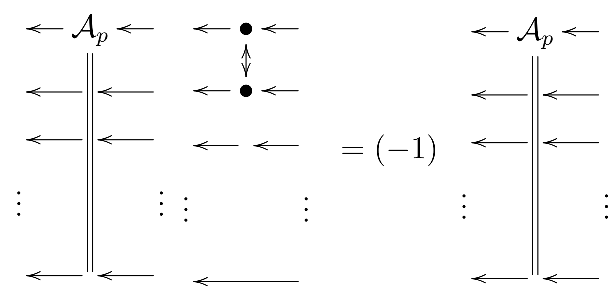
(16.23)

$$\boxed{\mathcal{A}_p \mathcal{A}_{[1,q]} = \mathcal{A}_p}$$



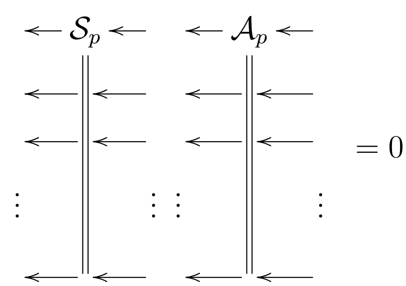
(16.24)

$$\boxed{\mathcal{A}_p \sigma_{(1,2)} = -\mathcal{A}_p}$$



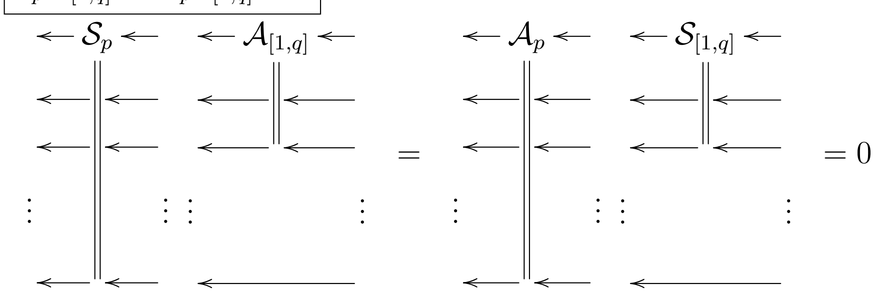
(16.25)

$$\boxed{\mathcal{S}_p \mathcal{A}_q = \mathcal{A}_p \mathcal{S}_q = 0}$$



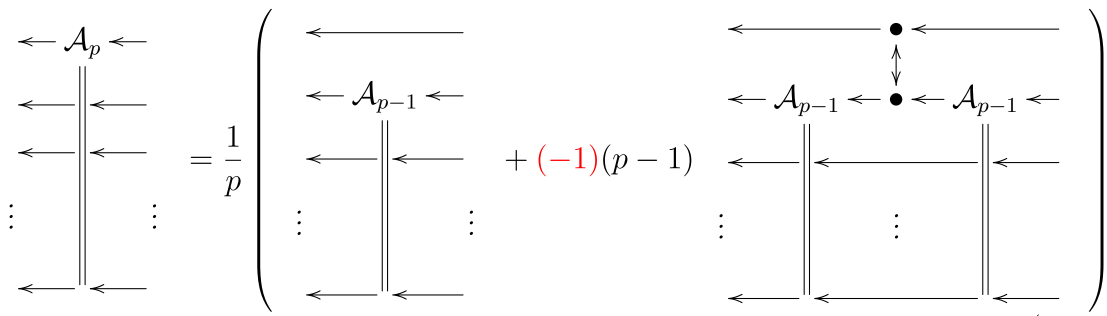
(16.26)

$$\boxed{\mathcal{S}_p \mathcal{A}_{[1,q]} = \mathcal{A}_p \mathcal{S}_{[1,q]} = 0}$$



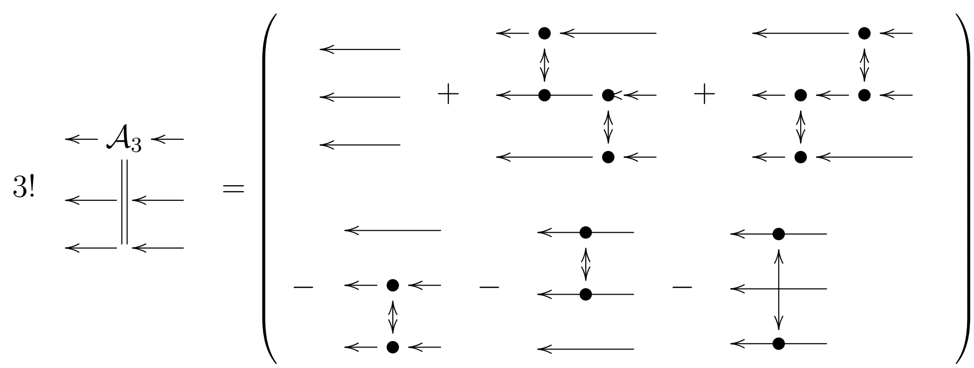
(16.27)

Claim 2

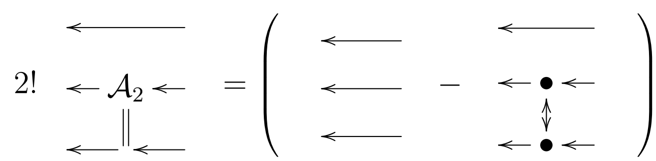


(16.28)

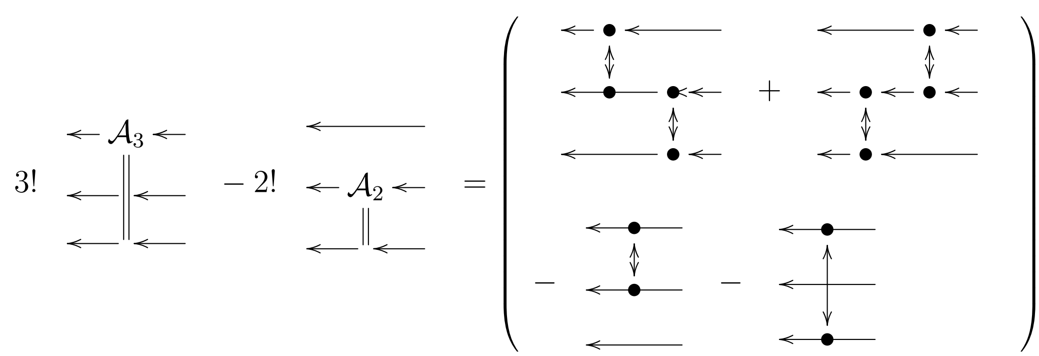
proof: We only prove it for $p = 3$.



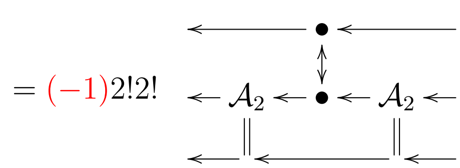
(16.29)



(16.30)

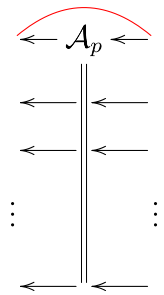


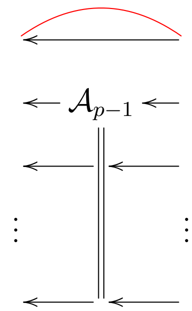
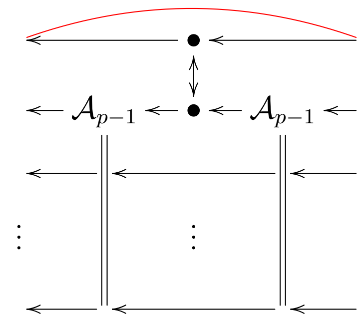
(16.31)

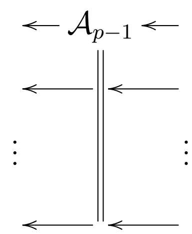


(16.32)

QED



$= \dfrac{1}{p} \Bigg($  $+ (-1)(p-1)$  $\Bigg)$ (16.33)

$= \dfrac{n + (-1)(p-1)}{p} \Bigg($  $\Bigg)$ (16.34)

$$\mathrm{tr}_{\underline{a}_1}\mathcal{A}_p = \frac{n-p+1}{p}\mathcal{A}_{p-1} \tag{16.35}$$

$$\mathrm{tr}_{\underline{a}_1,\underline{a}_2,\ldots,\underline{a}_k}\mathcal{A}_p = \frac{(n-p+1)(n-p+2)\ldots(n-p+k)}{p(p-1)\ldots(p-k+1)}\mathcal{A}_{p-k} \tag{16.36}$$

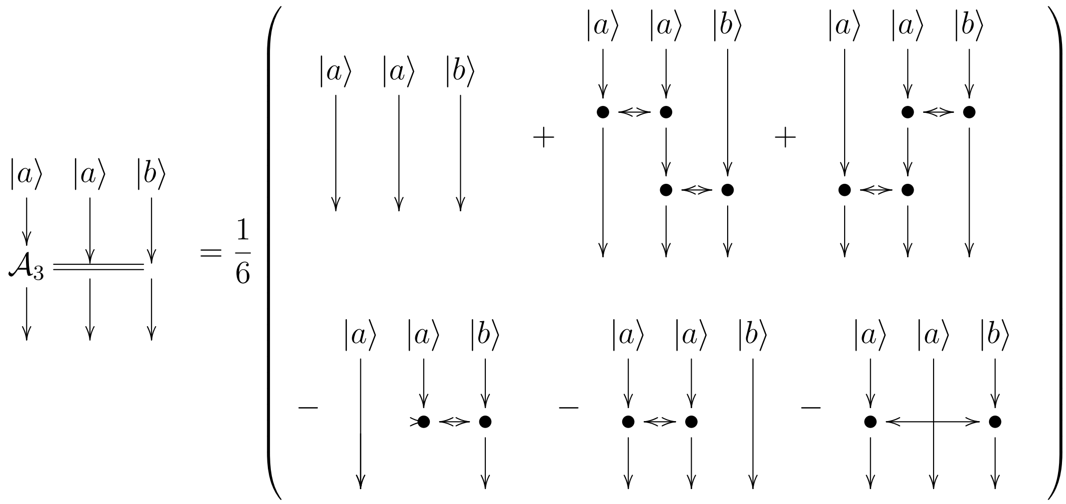
$$\begin{aligned} d_{\mathcal{A}_p} = \mathrm{tr}_{\underline{a}^p}\mathcal{A}_p &= \frac{\prod_{i=n-p+1}^{n} i}{p!} && (16.37) \\ &= \frac{\prod_{i=n}^{n-p+1} i}{p!} && (16.38) \\ &= \begin{cases} \frac{n!}{p!(n-p)!} = \binom{n}{p} & \text{if } p \leq n \\ 0 & \text{otherwise} \end{cases} && (16.39) \end{aligned}$$

For $p = 2 \leq n$,

$$d_{\mathcal{A}_2} = \binom{n}{2} \tag{16.40}$$

$$\mathcal{A}_p = 0 \text{ if } n < p \tag{16.41}$$

For example, for $n = 2$ and $p = 3$



(16.42)

$$\mathcal{A}_3|a,a,b\rangle = \frac{1}{6}\begin{pmatrix} |a,a,b\rangle + |a,b,a\rangle + |b,a,a\rangle \\ -|a,b,a\rangle - |a,a,b\rangle - |b,a,a\rangle \end{pmatrix} \tag{16.43}$$

$$= 0 \tag{16.44}$$

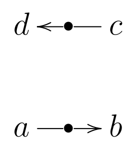
Chapter 17

Unitary Groups: COMING SOON

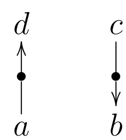
17.1 SU(n)

$$m(p,q) = \delta^a_b \sum_{a=1}^{n} (p_a)^* q_a \tag{17.1}$$

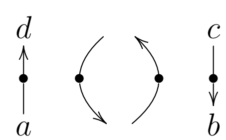
$$\mathbb{1}^{a,c}_{d,b} = \delta^a_b \delta^c_d = \tag{17.2}$$



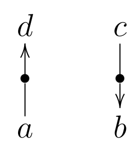
$$\uparrow\downarrow^{a,c}_{d,b} = \delta^a_d \delta^c_b = \tag{17.3}$$



$$\boxed{\uparrow\downarrow^2 = n \uparrow\downarrow} \tag{17.4}$$



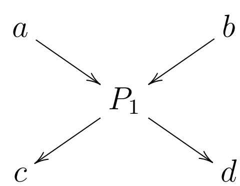
$= n$



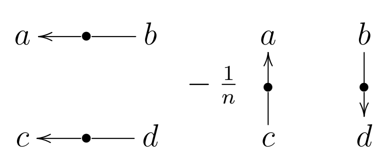
$$P_i = \sum_{j\neq i} \frac{M - \lambda_j}{\lambda_i - \lambda_j} \tag{17.5}$$

$\lambda_1 = n$

$$\boxed{P_1 = \frac{\uparrow\downarrow - n}{0 - n} = 1 - \frac{1}{n} \uparrow\downarrow} \tag{17.6}$$

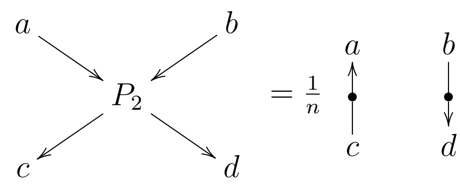


$=$

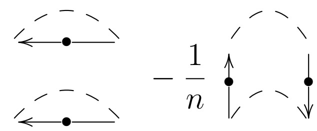


$\lambda_2 = 0$

$$\boxed{P_2 = \frac{\uparrow\downarrow - 0}{n - 0} = \frac{1}{n} \uparrow\downarrow} \tag{17.7}$$

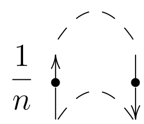


$$\mathrm{tr} P_1 = \tag{17.8}$$



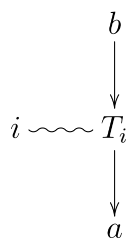
$$= n^2 - 1 \tag{17.9}$$

$$\mathrm{tr} P_2 = \tag{17.10}$$



$$= 1 \tag{17.11}$$

$$(T_i)_a^b = \tag{17.12}$$



$$T_i^\dagger = T_i \tag{17.13}$$

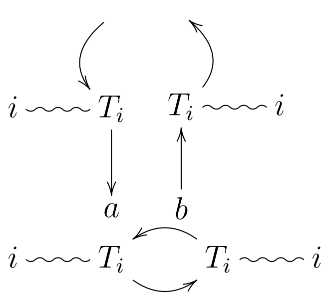
Claim 3

$$C_F \delta_a^b = (T_i T_i)_a^b = \frac{n^2 - 1}{n} \delta_a^b \tag{17.14}$$

proof:

$$(T_i T_i)_a^b = \sum_i \tag{17.15}$$

$$= \sum_i \tag{17.16}$$



QED

Chapter 18

Wigner Coefficients: COMING SOON

Chapter 19

Wigner-Ekart Theorem: COMING SOON

Chapter 20

Young Tableau: COMING SOON

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