Reference	Description
[Koch et al., 2002]	Comparison of functional and anatomical connectivity

Table 1: Newest references.

2 Terminology

Path analysis in functional neuroimaging is usually used to described the network between brain regions. In functional neuroimaging the term *structural equation modeling* (SEM) is more common. It has also been called *covariance structural equation modelling* (CSEM) [McIntosh and Gonzalez-Lima, 1994, Taylor et al., 2000]. The aspect revealed by path analysis in functional neuroimaging has been termed *effective connectivity* by *Karl J. Friston, —* in contrast to *functional connectivity* which describes the correlation among brain regions. *Systems-level neural modeling* has also been used to denote path analysis on the large scale brain regions [Horwitz et al., 1999, box on page 92].

3 General references

General introductions to structural equation modeling and path analysis are [Bollen, 1998b, Bollen, 1998a].

The "Computational approaches to network analysis in functional imaging" special issue of the journal *Human Brain Mapping*, volume 2, numbers 1 and 2, 1994, contains 8 contributions, e.g., [McIntosh and Gonzalez-Lima, 1994, Gonzalez-Lima and McIntosh, 1994, Grafton et al., 1994, Friston, 1994, Alexander and Moeller, 1994, Horwitz, 1994].

An introduction to path analysis in functional neuroimaging is [Büchel and Friston, 1997].

A problem with structural equation modeling with BOLD fMRI is the 1/f noise and/or cardiac and respiratory noise that may cause nuisance connectivity.

4.1 Tools

Name	Description	References
Mx		http://www.vcu.edu/mx/
SPM2 DCM	Dynamic Causal Modeling as implemented in SPM2	[Friston et al., 2003, Friston, 2003]
LISREL		http://www.ssicentral.com/other/entry.htm

Table 3: Tools

4.2 Unclassi£ed

[Friston et al., 1995] “regression”.

[Sychra et al., 1994] PCA on fMRI.

Canonical correlation analysis are available in, e.g., in [Bullmore et al., 1996].

[Cordes et al., 2001]

[Büchel and Friston, 1998]: “variable parameter regression” and Kalman £ltering

		mus			
?	PET		Language processing		[Petersson et al., 2000]
CC	PET	Wernicke, Broca, others	Language production		[Horwitz et al., 2000b]
CC	fMRI	Voxels in Rolandic cortex, ventrolateral thalamus, anterior putamen correlated with the rest of the brain	Motor		[Mopritz et al., 2000]
Panel-/PLS	PET	Left cerebellum, left superior fronal cortex	Eyeblink conditioning		[Easdon and McIntosh, 2000]
PLS	PET		Short-term memory wrt. age		[Della-Maggiore et al., 2000]
SEM	fMRI	5: VEC, PFC, SMA, IFG, IPL	Semantic decision, subvocal rehearsal	Model order determination by P-values, AIC and Bollen's "parsimonious £t index"	[Bullmore et al., 2000]
SEM	PET	?	?		[Nezafat et al., 2001]
?	fMRI	9: EC, BA37, IPS, SMA, FEF, VPC, IFG, PSTS, AG	Implicit language processing		[McKiernan et al., 2001]

Table 4: Path analyses in functional neuroimaging. VEC: ventral extrastriate cortex, PFC: prefrontal cortex, SMA: supplementary motor area, IFG: Interior frontal gyrus, IPL: Inferior parietal lobule.

are indicated by dotted lines.

```
digraph ObjectVision {
    rankdir=LR
    "17/18" -> "19v"
    "17/18" -> "19d" [style=dotted]
    "19v" -> "37"
    "19v" -> "19d"
    "19d" -> "7" [style=dotted]
    "19d" -> "46" [style=dotted]
    "37" -> "21"
    "37" -> "7" [style=dotted]
    "7" -> "21"
    "7" -> "46" [style=dotted]
    "21" -> "46"
    "46" -> "19v" [style=dotted]
}

digraph SpatialVision {
    rankdir=LR
    "17/18" -> "19v"
    "17/18" -> "19d"
    "19v" -> "37"
    "19v" -> "19d"
    "19d" -> "7"
    "19d" -> "46"
    "37" -> "21"
```

In [McIntosh and Gonzalez-Lima, 1994] interhemispheric functional models is considered for the same task.

A.2 Motor system

Motor system connectivity is examined by [Grafton et al., 1994] who used a cortical-subcortical network proposed by [Alexander et al., 1990, DeLong, 1990]. Some of the results from a LISREL estimation are displayed in £gure 3 and the corresponding *dot* £le is shown below.

```
digraph GraftonS1994Network {
        subgraph clusterNormalMovement {
                label="Normal subjects, Movement task";
                ranksep=0.75;
                { rank = same;
                        NM1 [label="SMA & Cingulate\n Motor Areas" ];
                        NM2 [label="Motor cortex"];
                }
                NM3 [label="Putamen"]
                { rank = same;
                        NM4 [label="Globus pallidus"];
                        NM5 [label="Ventrolateral\n Thalamus"];
                }
                NM1 -> NM2
                NM1 -> NM3 [style=dotted]
                NM1 -> NM5
                NM2 -> NM3 [style=dotted]
                NM2 -> NM5 [style=dotted]
```

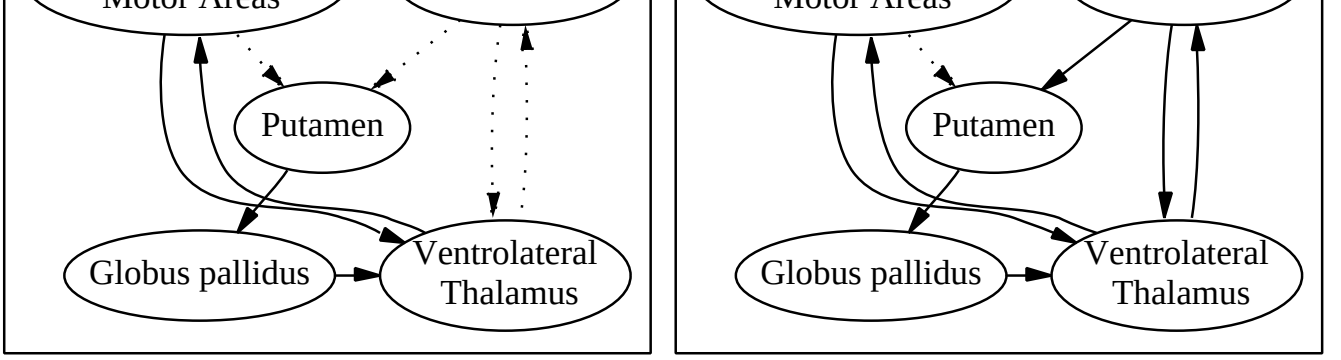

Figure 3: Movement network.

A.3 Cognition

A visual implicit language processing network:

```
digraph McKiernanK2001Development {
    rankdir=LR
    IFG -> VPC
    SMA -> VPC
    FEF -> SMA
    FEF -> VPC
```

References

[Alexander et al., 1990] Alexander, G. E., Crutcher, M. D., and DeLong, M. R. (1990). Basal ganglia thalamo-cortical circuits: Parallel substrates for motor, oculomotor, "pre frontal" and "limbic" functions. *Prog. Brain Res.*, 85:119–146.

[Alexander and Moeller, 1994] Alexander, G. E. and Moeller, J. R. (1994). Application of the scaled subpro£le model to functional imaging in neuropsychiatric disorders: A principal component approach to modeling brain function in disease. *Human Brain Mapping*, 2(1 and 2):79–94. ISSN 1065-9471.

[Biswal et al., 1997] Biswal, B., Hudetz, A. G., Yetkin, F. Z., Haughton, V. M., and Hyde, J. S. (1997). Hypercapnia reversibly suppresses low-frequency ¤uctuations in the human motor cortex during rest using echo-planar MRI. *Journal of Cerebral Blood Flow and Metabolism*, 17(3):301–308. PMID: 9119903.

[Biswal et al., 1995] Biswal, B., Yetkin, F. Z., Haughton, V. M., and Hyde, J. S. (1995). Functional connectivity in the motor cortex of resting human brain using echo-planar mri. *Magnetic Resonance in Medicine*, 34(4):537–541. PMID: 8524021. ISSN 0740-3194.

[Bollen, 1998a] Bollen, K. A. (1998a). Path analysis. In Armitage, P. and Colton, T., editors, *Encyclopedia of biostatistics*, pages 3280–3284. John Wiley & Sons, West Sussex, England. ISBN 0471975761.

[Bollen, 1998b] Bollen, K. A. (1998b). Structural equation models. In Armitage, P. and Colton, T., editors, *Encyclopedia of biostatistics*, pages 4363–4372. John Wiley & Sons, West Sussex, England. ISBN 0471975761.

[Büchel et al., 1999] Büchel, C., Coull, J. T., and Friston, K. J. (1999). The predictive value of changes in effective connectivity for human learning. *Science*, 283(5407):1538–1541. PMID: 10066177. ISSN 0036-8075.

[DeLong, 1990] DeLong, M. R. (1990). Primate models of movement disorders of basal ganglia origin. *Trends in Neurosciences*, 13(281–285).

[Easdon and McIntosh, 2000] Easdon, C. and McIntosh, A. R. (2000). Measuring dynamic connectivity in eyeblink conditioning: A panel analysis. *NeuroImage*, 11(5, part 2):S572. Sixth Annual Meeting of the Organization For Human Brain Mapping.

[Friston, 1994] Friston, K. J. (1994). Functional and effective connectivity in neuroimaging: A synthesis. *Human Brain Mapping*, 2(1 and 2):56–78. ISSN 1065-9471.

[Friston, 2003] Friston, K. J. (2003). Dynamical causal models. In Frackowiak, R. S. J., Friston, K. J., Dolan, R., and Price, C., editors, *Human Brain Function*, chapter 22. Academic Press, second edition. http://www.£l.ion.ucl.ac.uk/spm/HBF2/pdfs/Ch22.pdf. ISBN 0122648412.

[Friston et al., 2003] Friston, K. J., Harrison, L., and Penny, W. (2003). Dynamic causal modelling. *NeuroImage*, 19(4):1273–1302. PMID: 12948688.

[Friston et al., 1995] Friston, K. J., Ungeleider, L. G., Jezzard, P., and Turner, R. (1995). Characterizing modulatory interactions between V1 and V2 in human cortex with fMRI. *Human Brain Mapping*, 2:211–224.

[Gonzalez-Lima and McIntosh, 1994] Gonzalez-Lima, F. and McIntosh, A. R. (1994). Neural network interactions related to auditory learning analyzed with structural equation modeling. *Human Brain Mapping*, 2(1 and 2):23–44. ISSN 1065-9471.

[Grafton et al., 1994] Grafton, S. T., Sutton, J., Couldwell, W., Lew, M., and Waters, C. (1994). Network analysis of motor system connectivity in parkinson's disease: Modulation of thalamocortical interactions after pallidotomy. *Human Brain Mapping*, 2(1 and 2):45–55. ISSN 1065-9471.

and Müller-Gärtner, H. (1999). Network analysis in episodic encoding and retrieval of word-pair associates: a PET study. *European Journal of Neuroscience*, 11(9):3293–3301. PMID: 10510193.

[Lowe, 1999] Lowe, M. J. (1999). Functional connectivity with continuous state fMRI assessed with structural equations. *NeuroImage*, 9(6):S197.

[McIntosh, 1998] McIntosh, A. R. (1998). Understanding neural interactions in learning and memory using functional neuroimaging. *Ann. New York Academy of Sci.*, 855:556–571. PMID: 9929651.

[McIntosh, 1999] McIntosh, A. R. (1999). Mapping cognition to the brain through neural interactions. *Memory*, 7(5–6):523–548. PMID: 10659085.

[McIntosh and Gonzalez-Lima, 1991] McIntosh, A. R. and Gonzalez-Lima, F. (1991). Structural modeling of functional neural pathways mapped with 2-deoxyglucose: Effects of acoustic startle habituation on the auditory system. *Brain Research*, 547(2):295–302. PMID: 1884204.

[McIntosh and Gonzalez-Lima, 1992] McIntosh, A. R. and Gonzalez-Lima, F. (1992). Structural modeling of functional visual pathways mapped with 2-deoxyglucose: Effects of patterned light and footshock. *Brain Research*, 578(1–2):75–86. PMID: 1511292. ISSN 0006-8993.

[McIntosh and Gonzalez-Lima, 1994] McIntosh, A. R. and Gonzalez-Lima, F. (1994). Structural equation modeling and its application to network analysis in functional brain imaging. *Human Brain Mapping*, 2(1 and 2):2–22. ISSN 1065-9471.

[McIntosh et al., 1994] McIntosh, A. R., Grady, C. L., Ungerleider, L. G., Haxby, J. V., Rapoport, S. I., and Horwitz, B. (1994). Network analysis of cortical visual pathways mapped with PET. *Jornal of Neuroscience*, 14(2):655–666. PMID: 8301356.

http://www.math.mcgill.ca/ keith/HBM98/HBM98.ps. Short description of determination of functional connectivity by examining the cross-correlation between voxels and determing a threshold setting from random £eld theory. The method is exempli£ed on a positron emission tomography data set.